NASA CR-
144366

(NASA-CR-144366) SPACE SHUTTLE/FOOD SYSTEM STUDY. VOLUME 1: TECHNICAL VOLUME, CVEN STUDY Final Report (Fairchild Republic Div., Farmingdale, N.Y.) 97 p HC $4.75 CSCL 06K G3/54
N75-29778
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FINAL REPORT
SPACE SHUTTLE/ FOOD SYSTEM STUDY

VOLUME I - TECHNICAL VOLUME

OVEN STUDY

MAY 24, 1975

prepared for

NATIONAL AERONAUTICS and SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas 77058

Contract NAS9-13138

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FAIRCHILD
REPUBLIC DIVISION

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1.0 INTRODUCTION

The baseline space shuttle galley is defined by Fairchild Republic Company report number MS148N0008 entitled "End Item Specification, Part 1, Performance Requirements for the Space Shuttle Galley" dated 13 September 1974. This report was prepared under subcontract to The Pillsbury Company (TPC Contract P033349) as a part of NASA Prime Contract NAS9-13138. The report consists of two volumes as follows: Volume I Technical Volume, Volume II Supporting Appendices. This baseline system was designed to utilize lightweight rehydratable foods, to be prepared for consumption by rehydration with chilled or hot water. At a temperature of 160°F, the hot water produces a rehydrated food at a temperature of approximately 150°F. To maintain this temperature during the 15 -20 minutes required for complete rehydration, the food is placed in a holding oven designed to simply balance the heat loss.

This study is an add-on to the above noted NASA prime contract and TPC subcontract and has been prepared in order to consider the impact of an extension of food types to include thermostabilized food at ambient temperature, and frozen foods at 0°F.

2.0 STATEMENT OF WORK

2.1 General

The baseline galley system was designed to handle a maximum of 42 man-day capability plus contingencies. For a six day mission this translates into three seven man meals per day for six days. Since the system is intended to handle rehydratable meals only, the oven was sized to accept seven meals at a time, each meal consisting of three rehydratables for a total of twenty-one food packages. Prior to insertion in the warming oven, each food package has had hot water added at 160°F and the oven is then required to hold this food at 150°F for 15-20 minutes in order to insure complete rehydration and a serving temperature of 135-145°F.

The introduction of frozen foods at 0°F and thermostabilized foods at ambient temperatures (70°F) will obviously have an impact on the oven, the galley design, the weight, volume, and power requirements, the water volume and temperature requirements, crew time-lines, and meal preparation times. Some of these impacts will be in a favorable direction, (e.g., hot water requirements will be decreased) and some may result in penalties (e.g., weight, volume, power). Some advantages are not readily measurable, such as a more satisfying menu in terms of variety and taste (i.e., hedonics).

This study is intended to review the effect of various combinations of foods on the galley baseline. It also considers one additional baseline change in that food serving temperatures will be acceptable up to a maximum of 180°F instead of the original baseline requirement of 135°F-145°F.

2.2 Prior State of the Art

The only previous hot food preparation in space, other than hot water rehydration, utilized conduction heating. Crew sized compared to Shuttle was small and weight was not as critical a factor. In addition, each crewman prepared his own meal as opposed to the Shuttle conception of a single crewman preparing as many as seven meals. Further, the cabin environment was not earthlike in regard to composition or pressure so a relatively low temperature limit was imposed on moist food. Conduction heating analyses were made by several groups (1, 2, 3) but were not comprehensive in that if frozen foods were considered, the change of state was neglected or limits on power input were not imposed.

A portion of a Skylab heating tray was obtained from NASA-JSC and vendors of oven components have been contacted to establish the industry current state of the art.

1. AMRL-TDR-63-135 "Method of Heating Foods During Aerospace Flight", MRD Div, General American Transportation Corporation, 1963
2. NASA-CR-134040 "Heating of Food in Modified Atmospheres", Purdue University, 1973
3. NASA-CR-134380 "Characterization of Heat Transfer in Nutrient Materials", University of Houston, 1973

2.3 Objectives

The specific objectives of this study, as outlined in the Statement of Work are:

1. Assess weight, volume, and power penalties associated with heating thermostabilized and frozen foods by means of:
   a. Hot air convection heating system
   b. Conduction heating system
2. Assess the impact on crew/galley interface and meal preparation timelines of the above described systems.

In order to accomplish this basic objective designs of the most efficient means of accomplishing the heating requirement within the guidelines herein presented, were pursued and developed sufficiently to determine the associated impact with a high degree of confidence.

2.4 Design Guidelines

The following guidelines and assumptions were used in performing the study:

1. All thermostabilized food will be in size 401 x 105 aluminum cans and stored at cabin ambient (assumed at 70°F)
2. All frozen food will be in size 401 x 105 aluminum cans and stored at 0°F.
3. All rehydratable food will be in 4 x 4 x 1.03 plastic packages and stored at cabin ambient. Temperature after hot water rehydration will be 150°F.
4. The mix of food items for oven analysis purposes was assumed as follows:
   a) Two thermostabilized plus one frozen item/man-meal for two dining periods/day, plus
   b) Any combination of thermostabilized and rehydratable items totaling three, for one dining period/day.

   It was assumed that all seven crewmen have the same mix of food types at a given meal.

5. The maximum heating time in the range 70–140°F will be 30 minutes so that bacterial growth will be limited to safe levels.

6. Assumptions for thermal analysis

   a) Heating times will be the same for both frozen and thermostabilized food, that is the loading time will not be staggered.

   b) The maximum allowable food temperature at any point will be 180°F

   c) The maximum range of average temperatures for all food packages for the meal will be 145°F to 180°F. The following range of thermophysical properties was assumed:

      i) thermal diffusivity (thawed) 0.0054 to 0.0063 ft^2 hr

      ii) thermal diffusivity (frozen) 0.044 to 0.042 ft^2 hr

      iii) latent heat of fusion 129 to 90 BTU/lb

7. Crew may remove meals from the oven at varying times after the food has reached serving temperature. Max time will not exceed two hours at final temperature.

2.4.1 Convection Oven Guidelines

This study considered as a baseline for the convection oven a symmetrical oven as shown in Figure 2-1, in which the food packages are exposed to air at 180°F and at the same velocity. The food packages are held in a tray insert adaptable to either round cans or square packages, Figure 2-2. The oven control consists of an ON-OFF switch and timer. In addition to the baseline design the study was also to include the following:

1) Heating design to accommodate two thermostabilized items at 70°F each plus one frozen item at 0°F for one design condition; and any combination of rehydratables and/or thermostabilized items as an additional design condition.

2) Rehydratables may be inserted in the oven at 150°F.

3) Power, weight, and volume penalties to elevate temperatures of all items to 150°F - 180°F.

4) Analysis of time-line for meal preparation

CONVECTION OVEN

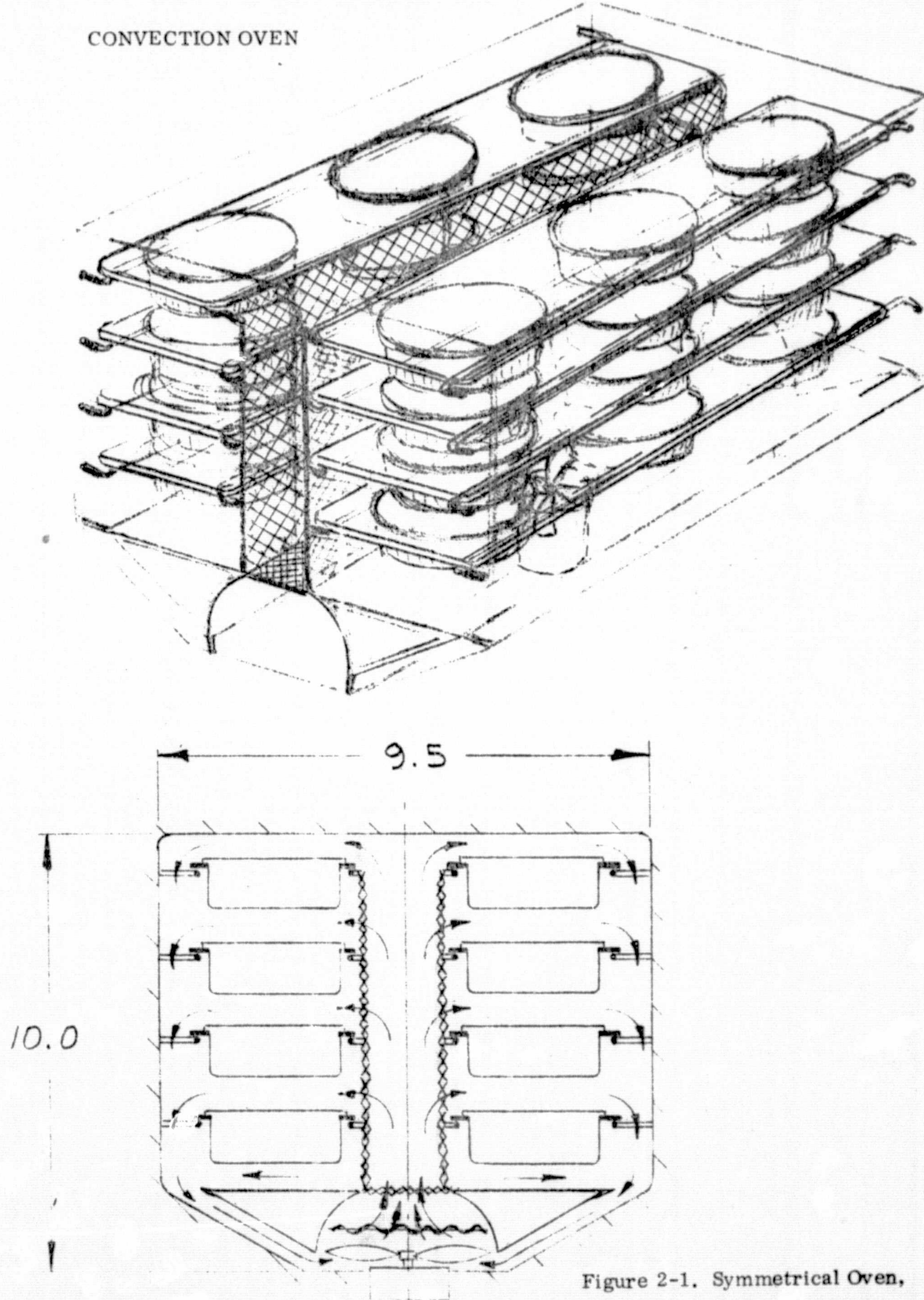


Figure 2-1. Symmetrical Oven, Linear Inserts.

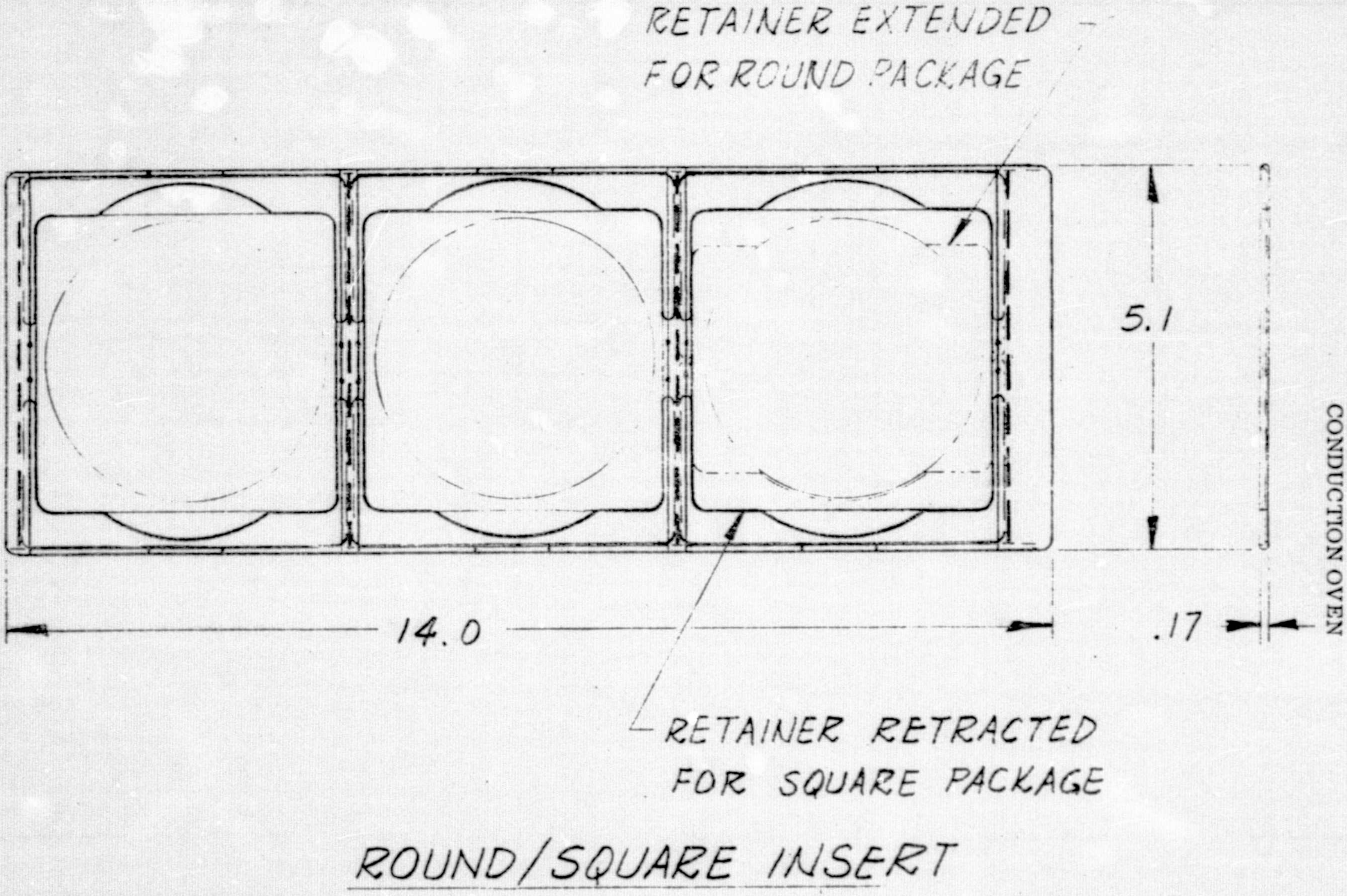


Figure 2-2. Food Tray Insert for 401 Cans and 4x4 Rehydratable Packages

2.4.2 Conduction Oven Guidelines

This study considered as a baseline a wired tray-insert concept as shown in Figure 2-3. The insert can accommodate three food packages and is convertible to any mix of round 401 x 105 cans or square 4" x 4" x 1.03" plastic package by means of a removable heater sleeve. The round heater sleeve maintains the can surface at 180°F; the square sleeve wall will be maintained at 150°F. The trays are inserted into an insulated cavity in the galley (the oven) where it receives power. Because of the range of food mixes given in the Design Guidelines 2.4, an inventory of 21-round and 21-square heater sleeves must be provided. The oven control consists of an ON-OFF switch and timer.

In addition to the baseline design the study was also to include:

1) Heating design to accommodate two thermostabilized items at 70°F each plus one frozen item at 0°F.

2) Power, weight and volume penalties to elevate temperature to 150°F - 180°F for above.

3) Power penalty to heat either 1, 2, or 3 thermostabilized food items and maintain temperature for balance of the rehydratables for the one dining period/day.

4) Food preparation and heating times requirements.

3.0 TECHNICAL APPROACH

Since the Space Shuttle baseline does not include a dining station or area set aside for dining as in Skylab, where electrical power or water is available, it necessarily follows that the galley must be self-sufficient and that all food must be in ready-to-eat condition when it leaves the galley area. It is therefore necessary that the heating system must be self-contained and that any power required for food or water heating must be provided within the galley.

CONDUCTION OVEN

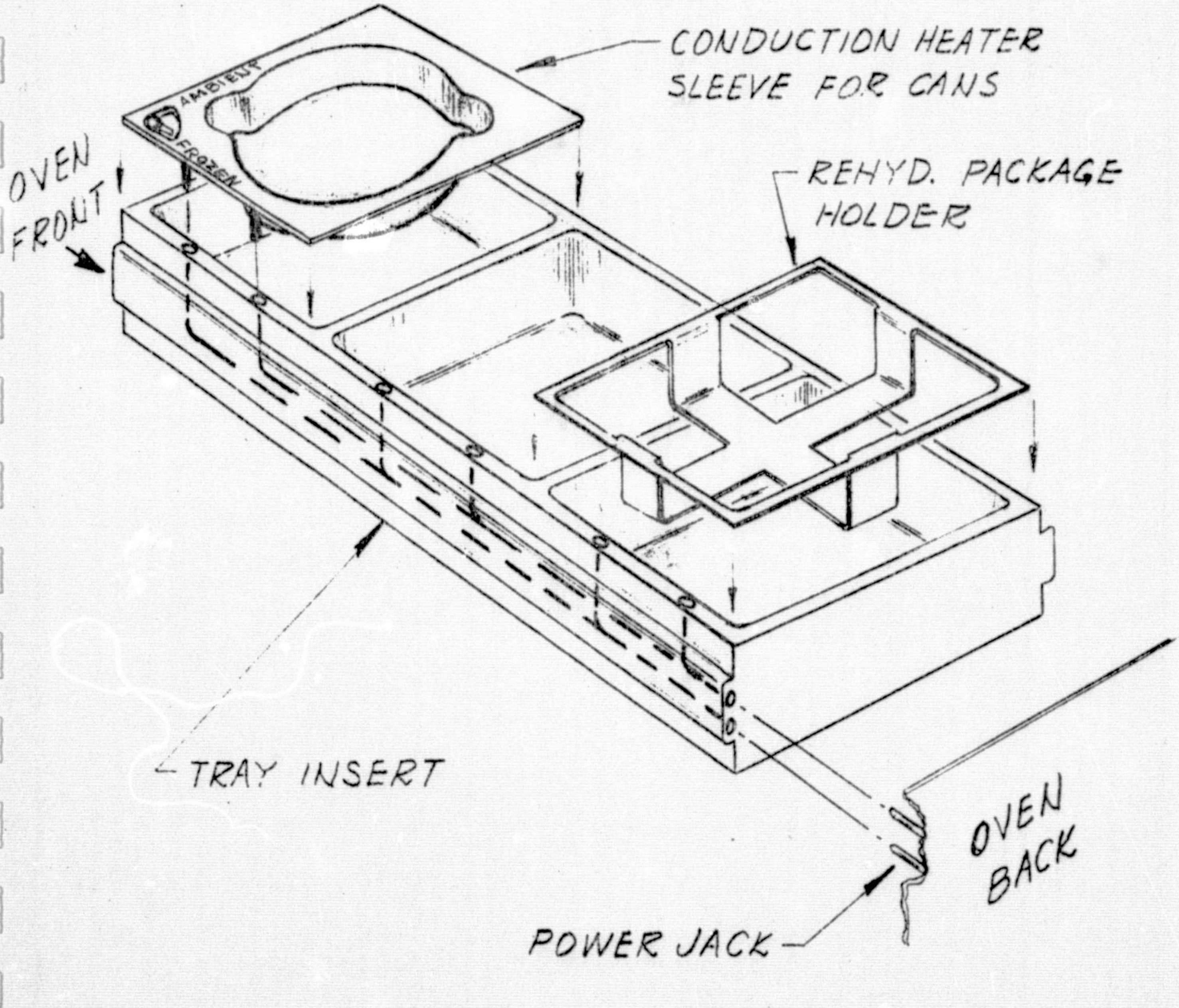


Figure 2-3. Wired Food Tray Insert

3.1 Convection Oven

The preliminary concepts were influenced to a great extent by an initial assumption that food serving temperatures should be uniform for all food types. Since frozen food requires almost three times the heat input as thermostabilized food to reach the same serving temperature, various alternatives for balancing heat input were considered:

a) Air temperature and surface heat transfer coefficient. Placing the thermostabilized can downstream of frozen cans will expose the thermostabilized can to lower air temperature. In addition, since there are twice as many thermostabilized as frozen food cans, the air velocity and therefore the heat transfer coefficient can conveniently be reduced for the thermostabilized cans. Figure 3-1, and 3-2 illustrate this approach.

b) Restricting exposed can surface area. Again 2:1 thermostabilized to frozen food can ratio can be utilized to limit heat input to the thermostabilized food by restricting the surface area exposed to the oven area. Figure 3-3 illustrates the approach.

c) Insulating thermostabilized cans. Heat input to the thermostabilized food cans can be restricted by placing an insulating sleeve around the can, Figure 3-4.

These strategies for balance are operationally undesirable in that they depend on a specific food type mix or specific placement in the oven. A symmetrical oven as shown in Figure 2-1 or 3-5 seemed most satisfactory and heat balance would be achieved by the use of insulating sleeves.

3.1.1 Convection Oven Study Selection

A significant design guideline which influenced the final selection was the relatively large latitude for the range of allowable food temperatures which was established as 145-180° F. This renders unnecessary some of the techniques for balancing heat inputs in the convection oven and makes for a simpler design. Since the maximum food temperature allowable is 180°, and since the food at the surface of the

CONVECTION OVEN

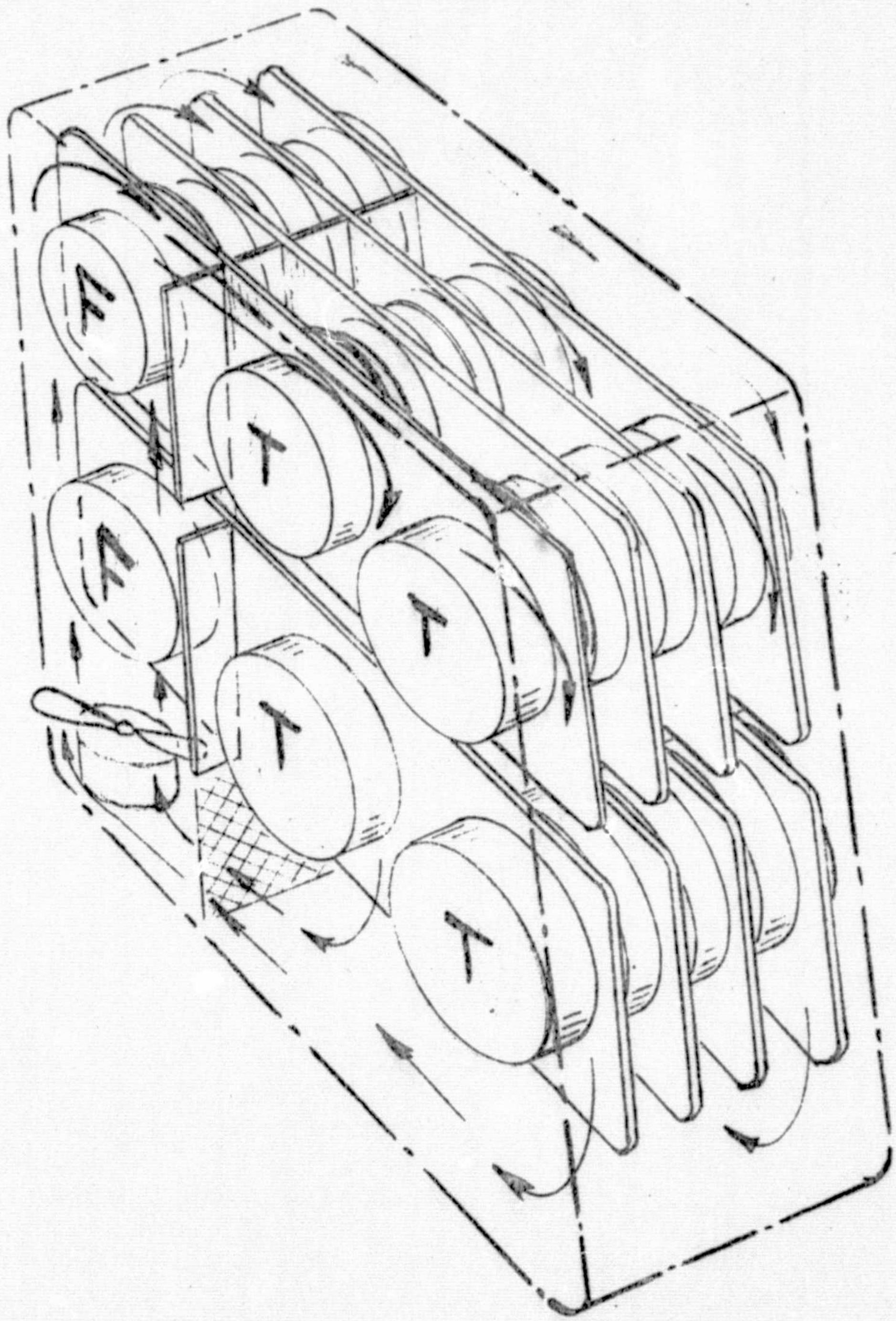


Figure 3-1. High Velocity Flow Over Frozen Food Cans, Cans In-Line

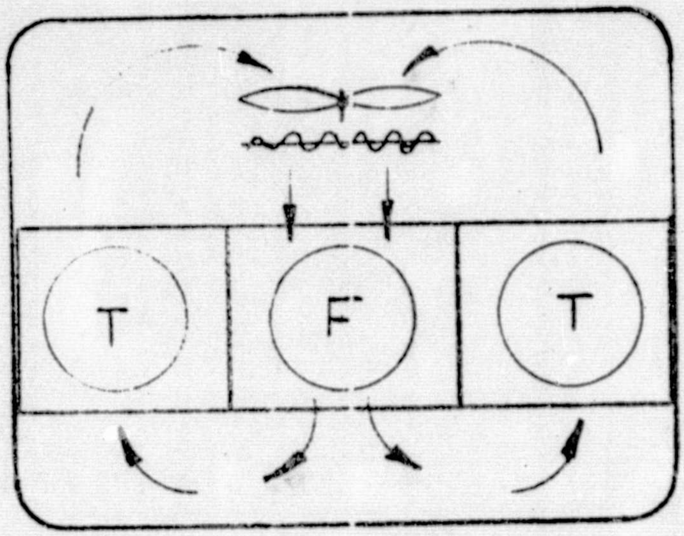


Figure 3-2. High Velocity Flow Over Frozen Food Cans, Thermostabilized Food Cans Not In-Line.

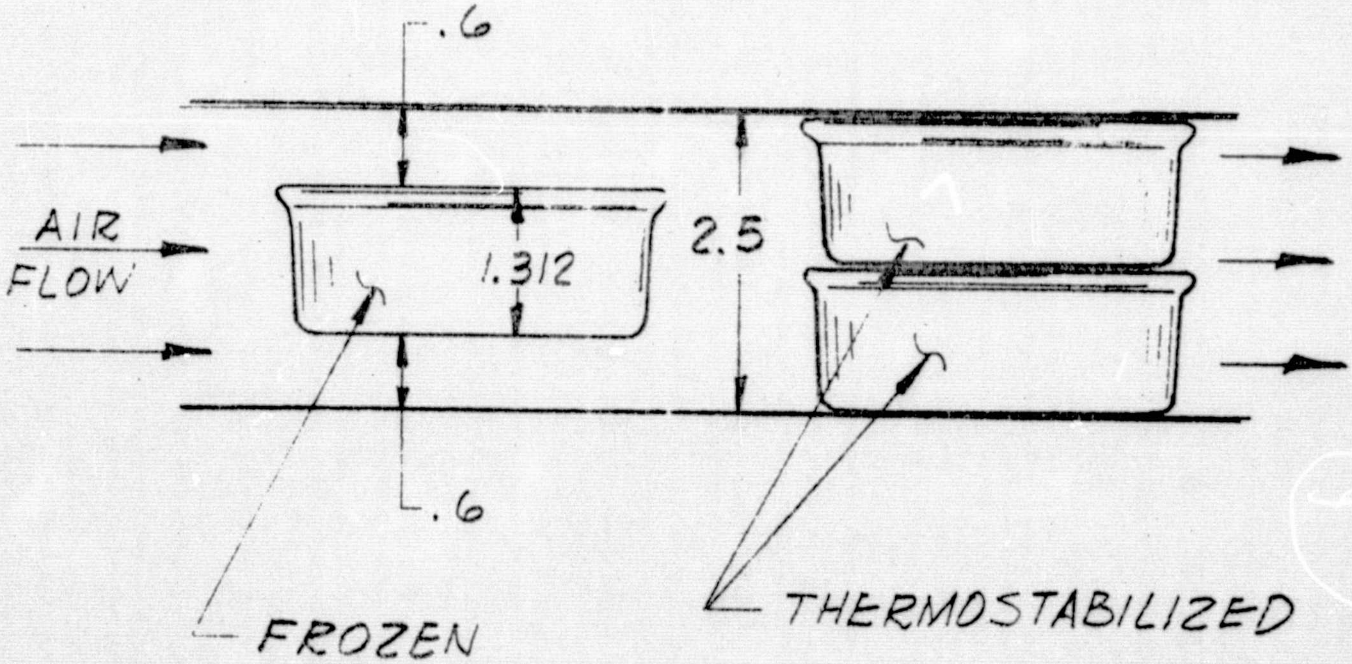


Figure 3-3. Surface Area Control of Heat Input. No Air Gap at Top, Bottom or Between Thermostabilized Cans.

CONVECTION OVEN

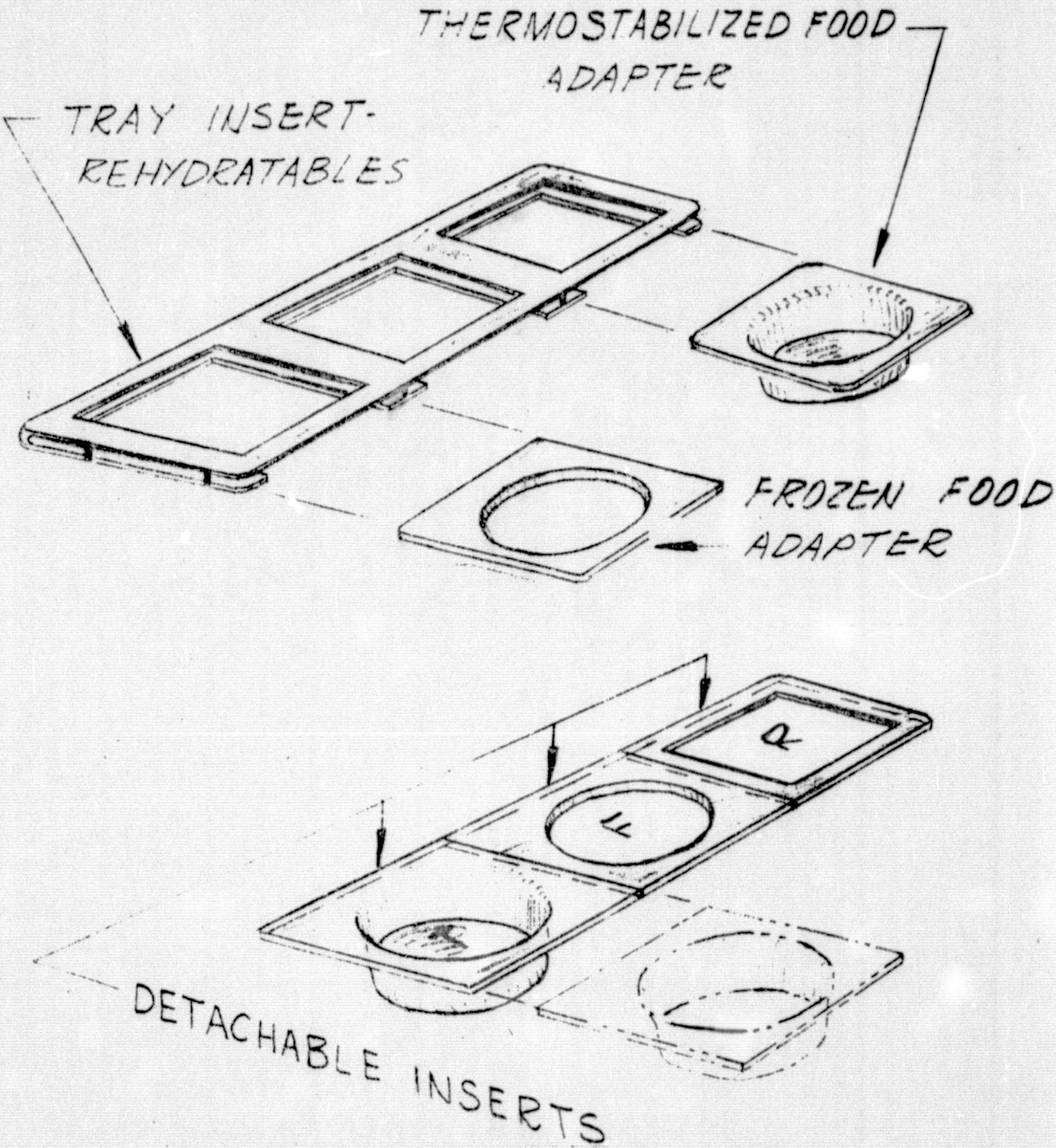


Figure 3-4. Insulating Sleeves for Thermostabilized Food Cans

CONVECTION OVEN

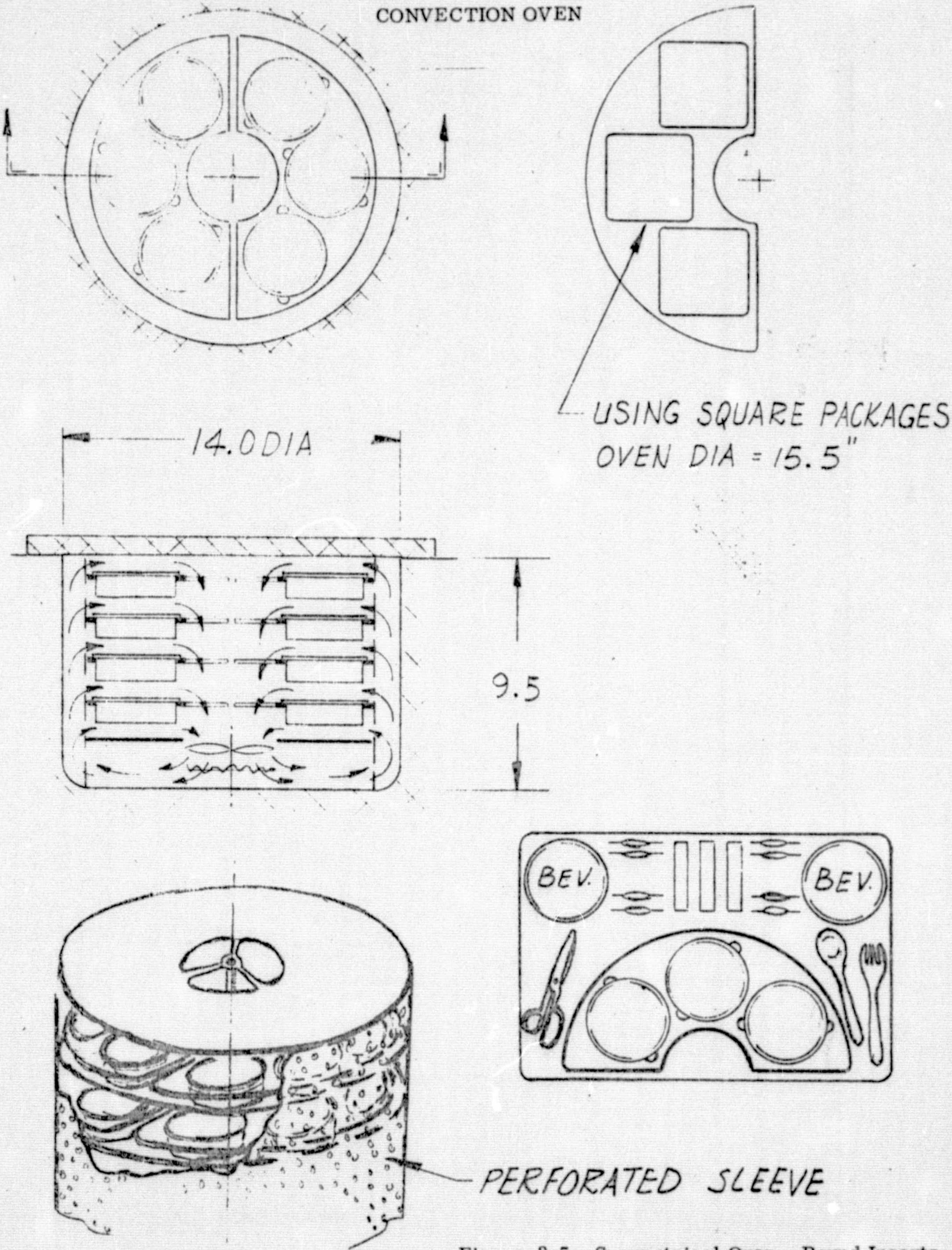


Figure 3-5. Symmetrical Oven, Round Inserts

can will soon approach the air temperature, the air temperature is limited to 180°F. The symmetrical oven shown in Figure 2-1 was chosen for detail study. To accommodate either round or square food packages a food tray insert shown in Figure 2-2 would be used. This supports three packages in the oven and attaches to the food tray for dining.

3.1.2 Initial Design Evaluation

The rationale for the convection oven selection was given in Section 3.1.1. A detailed fluid dynamic analysis was performed to minimize blower size and limit the major air pressure drop to the food tray insert region. The plenum dimensional requirements were then determined resulting in the oven outline shown in Figure 3-6. There are two parallel air loops with air passing over a single can before recycling. Because of the bilateral symmetry eight tray inserts are accommodated rather than the required seven. A separator is placed between the tray inserts to maintain separate flow paths. If all tray inserts were in place the insert itself performs this function. To maintain flow balance through each tray insert slot, regardless of the oven loading a variable resistance is placed at the inlet of the slot. This consists of two perforated plates - one fixed, the other movable and spring loaded. The relative position of the plates determine its unobstructed area fraction and flow resistance. When a tray insert is in place, the movable plate is positioned so that its openings are coincident with those of the fixed plate yielding the minimum flow resistance. Without a tray insert, the relaxed position of the movable plate creates a flow resistance equivalent to that of the food can - open plate combination.

The spacing between the can and separator is 1/8" and the flow through each tray insert slot is 50 CFM. This leads to a caulculated heat transfer coefficient of 4.3 BTU/ hr-ft^2 - °F. The total air flow is 400 CFM at a pressure drop of 0.92 in. H_2O.

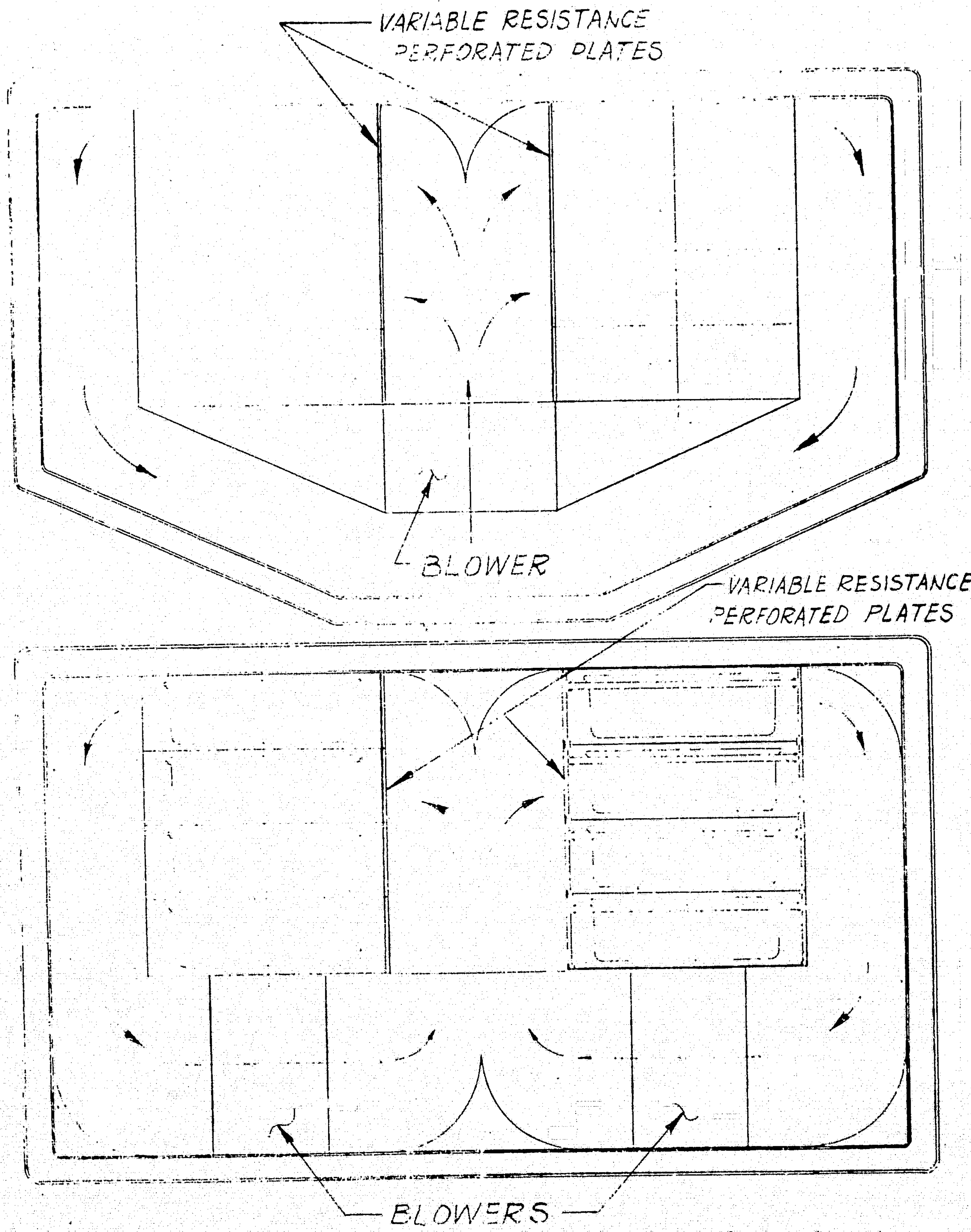


Figure 3-6 Initial Convection Oven Design, Front Views, Alternate Concepts

The useful volume fraction of the oven, i.e., the food tray insert volume compared to the total oven, is only 0.34. This seems unacceptably low and also would result in high oven weight. Consequently, a more efficient design was sought.

3.1.3 In-Line Convection Oven

A major improvement in volume utilization can be achieved by an in-line can arrangement. In this scheme the airstream flows past more than one can before recycling. The effect is to reduce the plenum volume significantly and results in a more efficient design. The original motivation for a single-can pass was to present each can with a uniform air temperature and flow condition so as to maintain good control of food temperature. The wide latitude of acceptable food temperature relieves this requirement. A typical design evolved is shown in Figure 3-7. In this series arrangement a plenum is required only at the narrow end of the oven. The air flows over three cans and turns and the pressure is stepped up before passing through the symmetrical other half. A somewhat more condensed version is shown in Figure 3-8. A further volume reduction is achieved by locating both fans in series at one end as shown in Figure 3-9. In all three designs the volume flow, since it is not a parallel arrangement is reduced to 75 CFM and the pressure drop is 3.5 in. H_2O. As in the original design flow balance through the insert is maintained by perforated plates, this time at the narrow end of the slot. Symmetry again leads to a capacity of eight inserts.

3.1.4 <u>Final Convection Oven Design</u>

An additional refinement of the in-line can design led to the final design to be analyzed for the purpose of comparison with the conduction oven and the baseline holding oven. In this design, exactly seven tray inserts are accommodated and the plenum volume is somewhat reduced by introducing the air at the side of the first can in line and having the air make two turns through the insert region. See Figure 3-10.

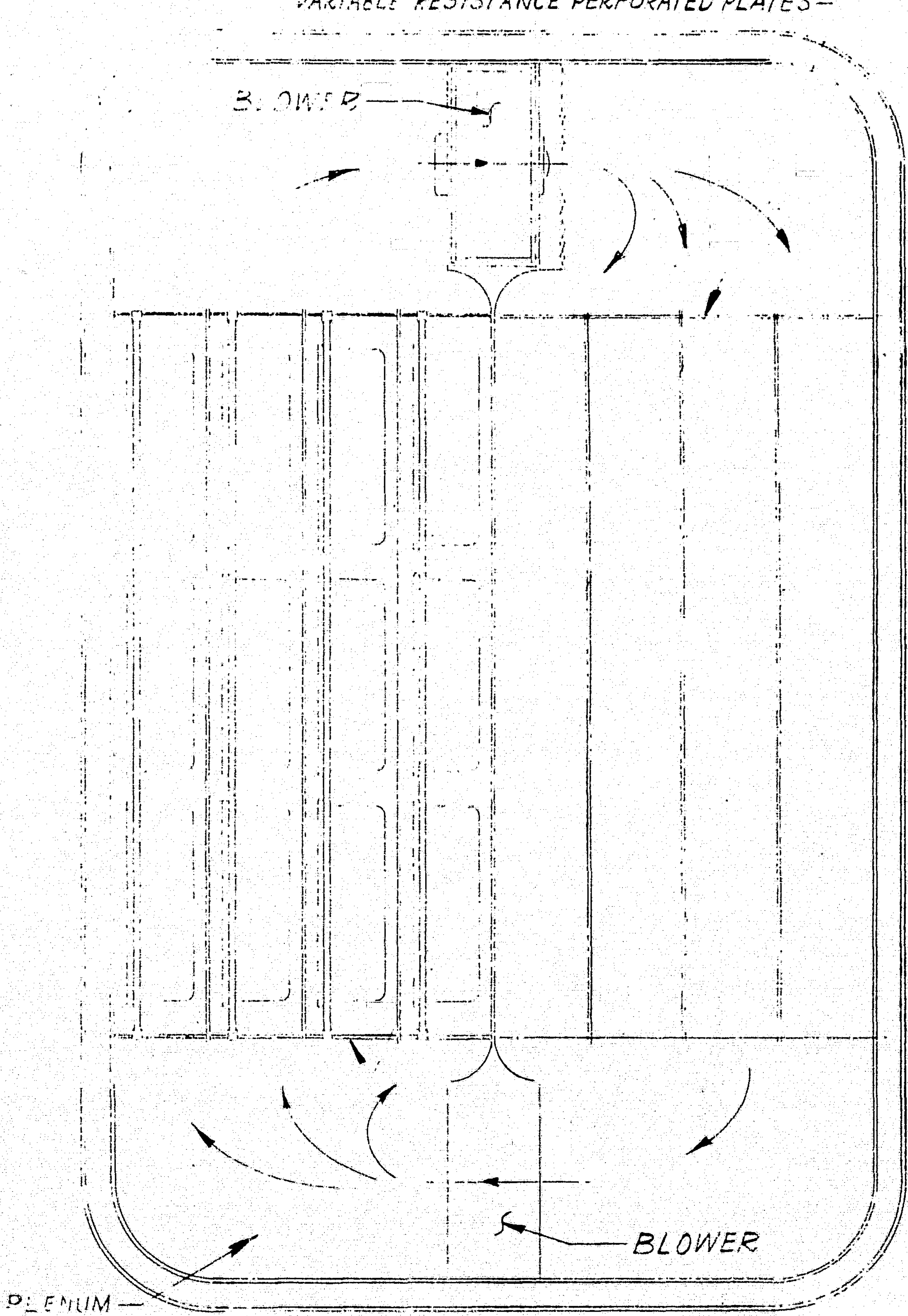


Figure 3-7. Convection Oven Preliminary Design

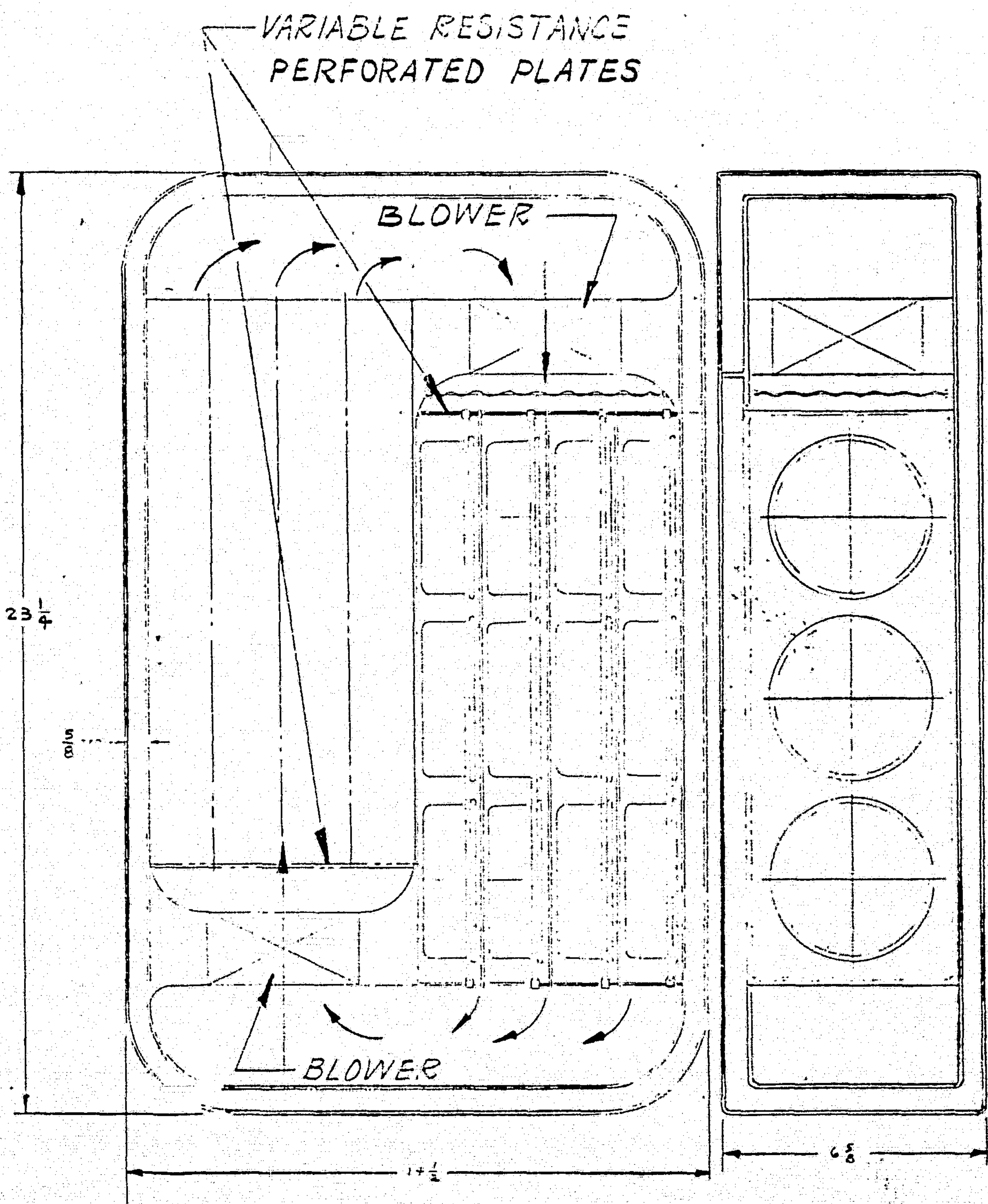


Figure 3-8. Convection Oven - Condensed Design

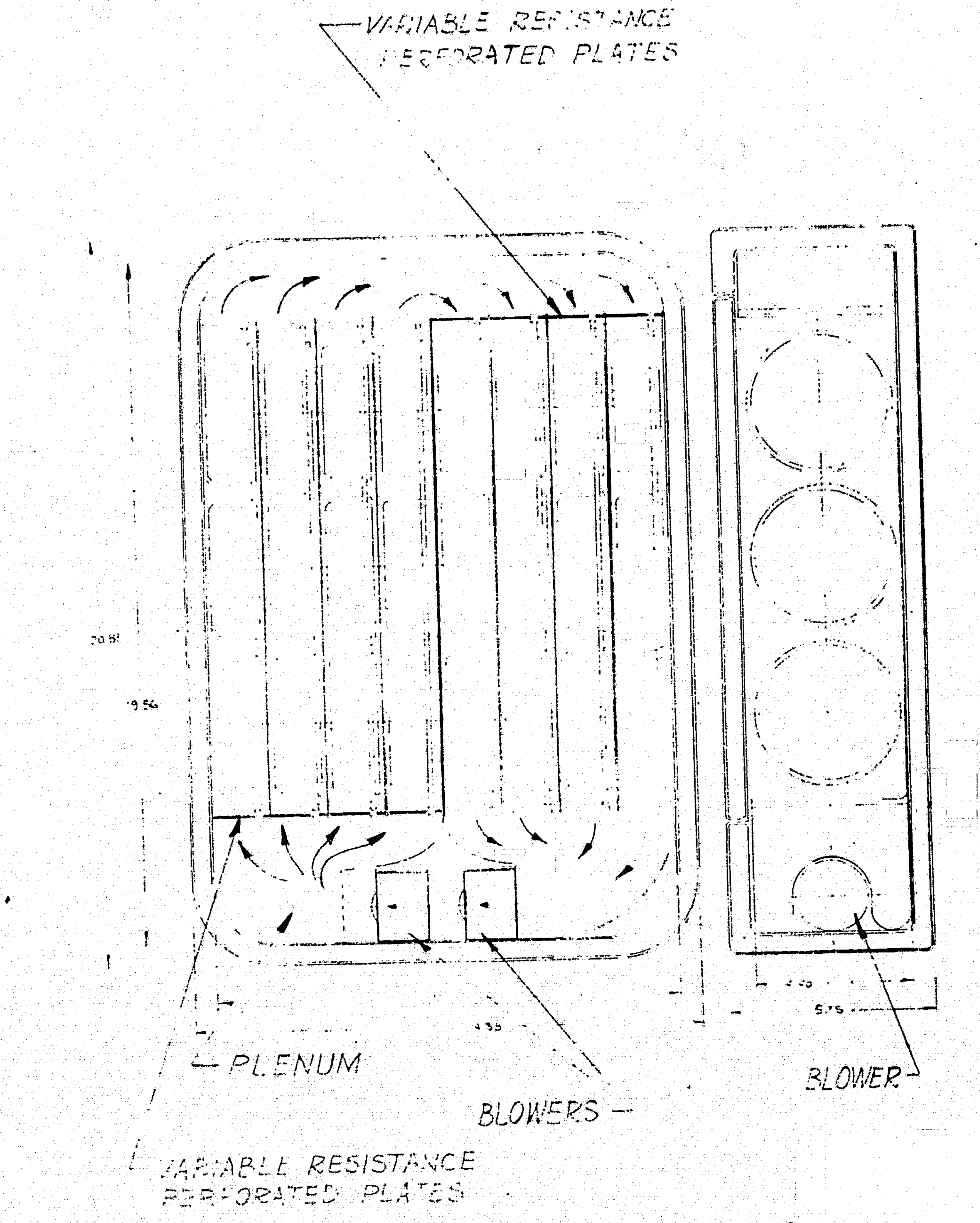


Figure 3-9. Convection Oven with Series Blowers

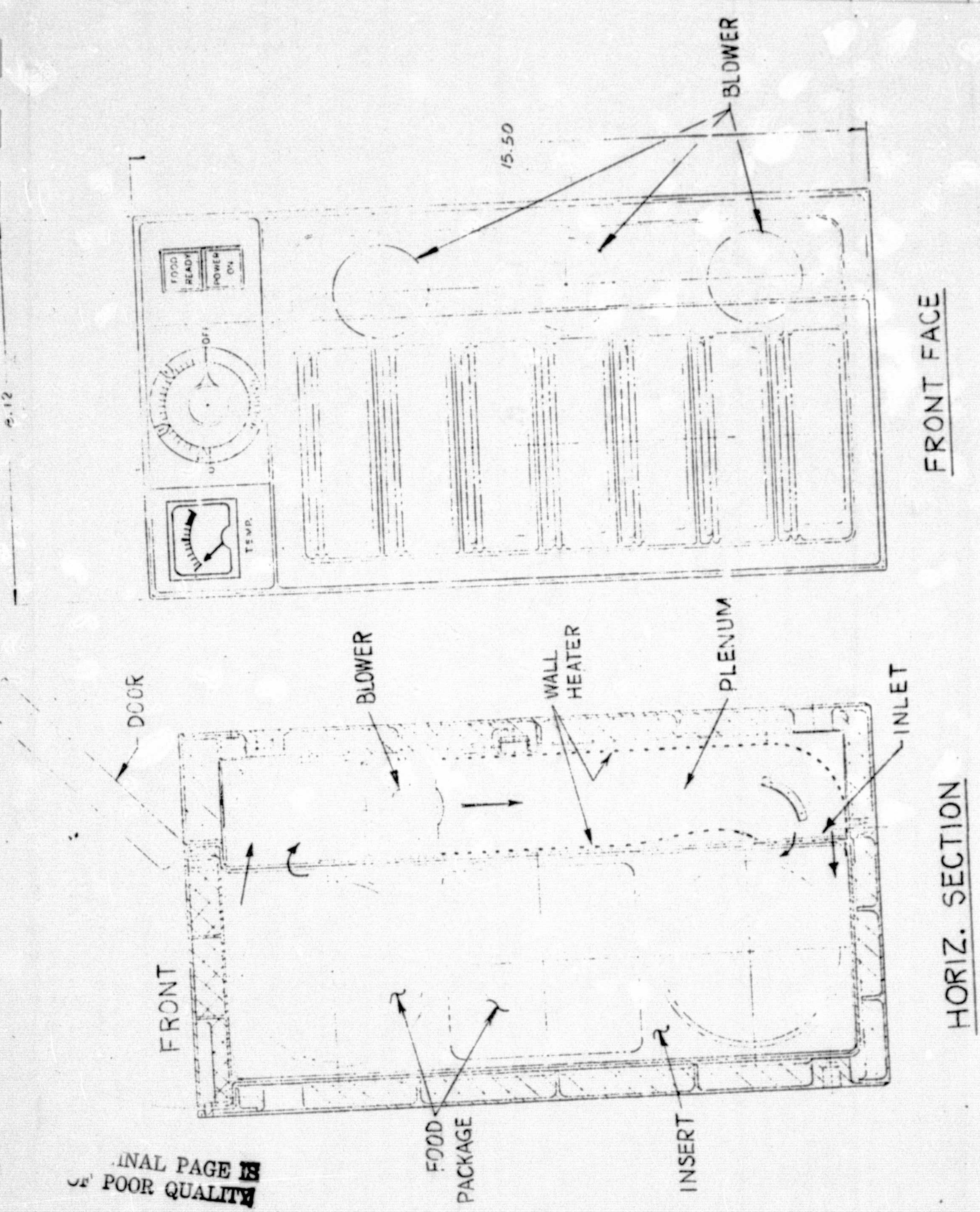


Figure 3-10a Parallel Convection Oven, Final Design

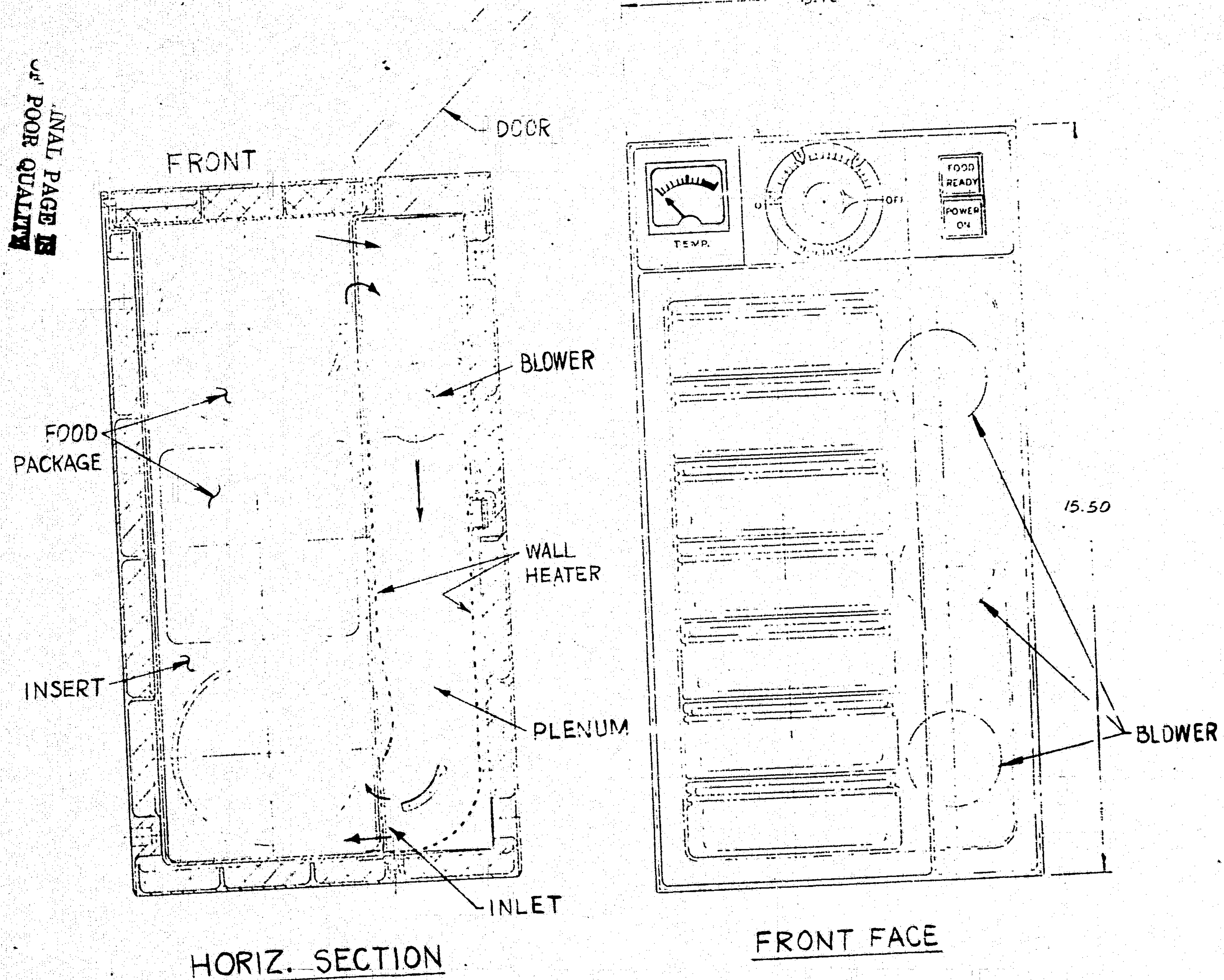


Figure 3-10a Parallel Convection Oven, Final Design

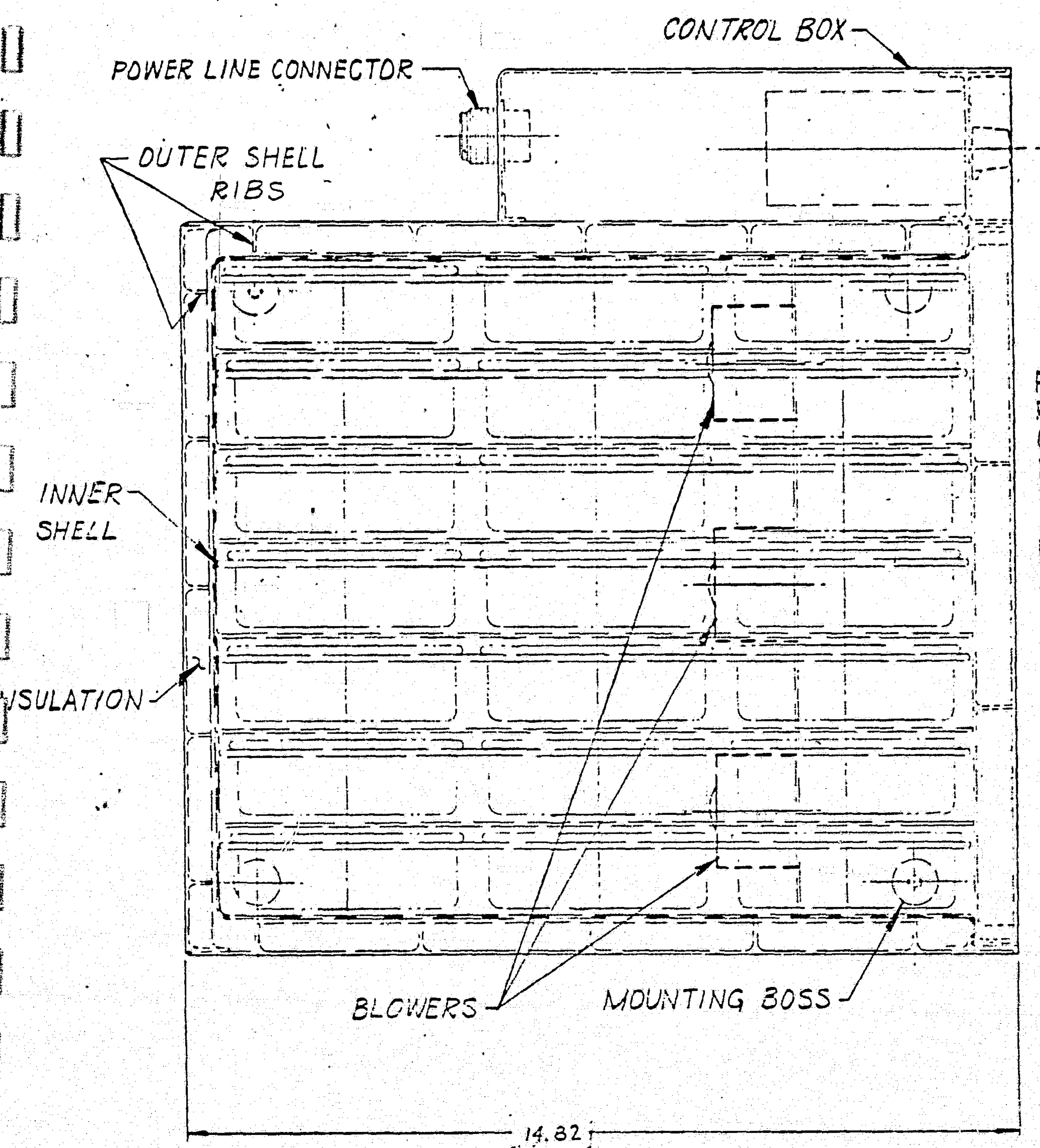


Figure 3-10b Parallel Convection Oven, Side View

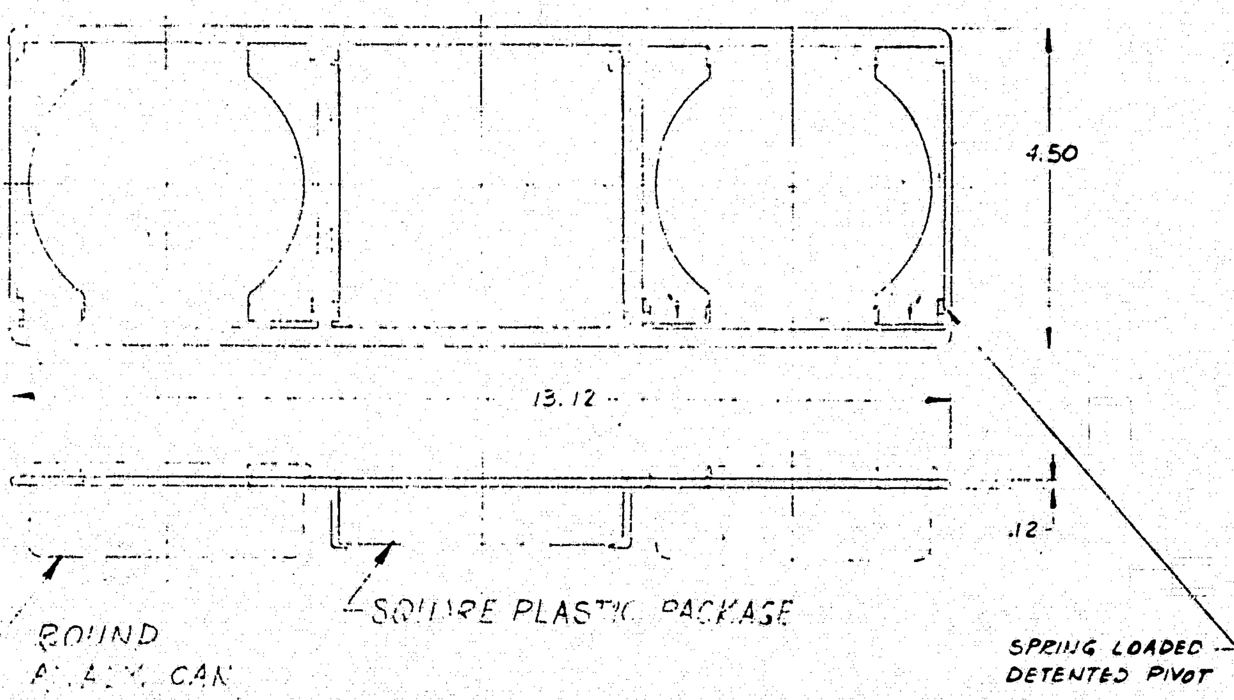


Figure 3-10c Convection Oven Tray Insert

Three parallel blowers are utilized with a combined flow of 125 CFM and pressure drop of 1.45 in. H_2O. The use of multiple blowers to supply the required air flow allows the selection of smaller blowers and provides a better flow distribution. A further advantage of multiple blowers is the possibility of oven usefulness if one blower should fail. Two fan operation would lead to a calculated drop in h of only 16%, resulting in minor performance degradation. The useful volume fraction of the final design is 0.67 which is an improvement of 97% over the starting point. If the seven meal requirement alone is considered, the initial oven useful volume fraction can be redefined as 0.30, and the final design will then represent an improvement of 133%.

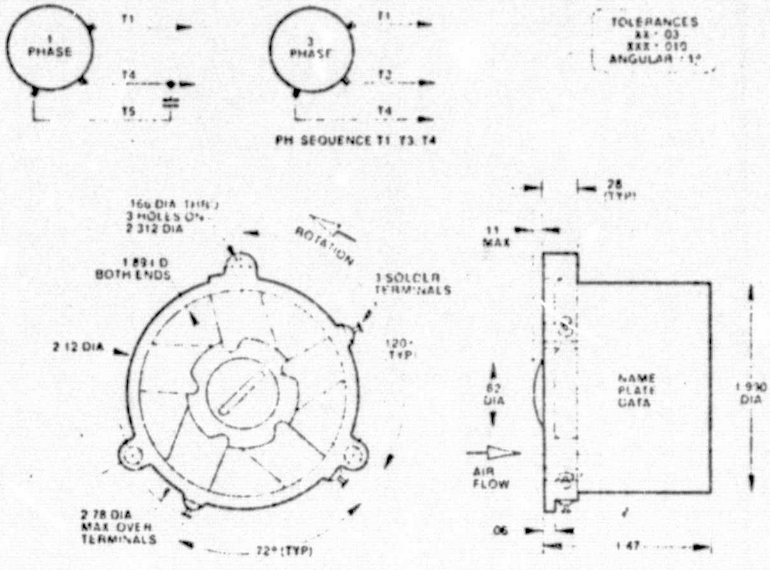
3.1.4.1 Blower Design

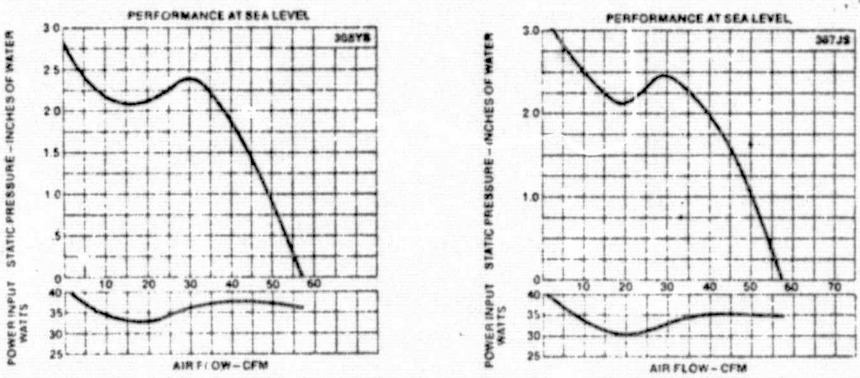
To achieve a heat transfer coefficient in the range of 4-5 BTU/hr-Ft^2 -°F, an air flow in the range of 90-125 CFM at a pressure drop of 0.75 - 1.45 in. H_2O is required. This load is divided by three parallel blowers each delivering one third the flow at the given pressure head. In the final design a vaneaxial fan similar to the Rotron Aximax 2 fulfills the requirement delivering a combined flow of 125 CFM at 1.45 in H_2O for a calculated value of h = 5. The blower is small, lightweight and has been used successfully in missile applications. The blower dimensions are 2" diameter x 1.5" length. It weighs 4.5 oz. and operates at 115/200V, 400 Hz, 3 phase, with a power input of about 35 watts. DC motors are ruled out because of their larger size and weight. Figure 3-11 gives the sea level performance curve for these fans and its physical dimensions. The heater and blowers are mounted as a shop replaceable assembly which can be removed and replaced by actuating a quick-disconnect and several fasteners.

3.1.4.2 Heater Design

3.1.4.2.1 Blower As a Heat Source

In all of the designs presented, the blower motor is inside the oven and consequently the blower power can be considered as a part of the heat supply. The blower can operate up to ambient temperatures of 257°F so that the 180°F oven air is sufficient derating. There will be some lag in the availability of all of this power until the blower warms up; however, its





Series	Part No Aximax 2	Part No Aximax 2H	Volts	Ph.	Hz	Cap[1] Mfd	Watts	Line Amps	Locked Rotor Amps	RPM	CFM	Max. Amb. °C
368YS	026948	026949	115	1	400	0.5	37.0	0.32	0.41	20,500	56	125
367JS	026950	026951	200	3	400	–	34.0	0.13	0.30	20,500	56	125

Figure 3-11 Blowers Performance Data

small mass will heat quickly. Toward the end of the food heating cycle the blower power would be sufficient for all the heat needs. After the food has reached temperature, the holding function can be achieved by either one or two fans to make up oven heat losses. If the oven power is taken as 500 watts, (see Section 3.1.4.4.2) then the combined blower power of 105 watts requires that the main heater supply the balance of approximately 400 watts.

3.1.4.2.2 Main Heater Element

It has been assumed that the general Shuttle specification which requires that equipment meet an explosive atmosphere test in accordance with MIL-STD-810, Method 511, Procedure I, using butane as fuel, is applicable. The auto-ignition temperature of butane mixtures is 806°F (4) and a margin of safety would require unsealed surfaces not to exceed perhaps 600°F. This requirement eliminates the use of small area - high temperature heaters such as filaments. The use of a finned heat exchanger is possible, but the power requirements can be met in a simpler way without an additional penalty in air pressure drop.

Thin foil-resistance-heaters can be placed on the plenum walls downstream of the blower. These heaters are made with a silicone support and insulation having operating temperatures up to 600°F. AC power is used to minimize wire and connector sizes. If the temperature is limited to 400°F to provide a margin of safety, then the required wall area based on an effective heat transfer coefficient of 5 and a temperature difference of 220°F is 180 square inches. The maximum wall temperature of 400°F would be obtained for a short time after the start of heating since the power requirements for heating decrease with time (Section 3.1.4.4.2). On the average, the wall temperature is nearly 350°F.

Having the outside heater wall at a temperature greater than 180°F would require more insulation that the other walls, but this is no problem and is easily met by the insulation thickness provided.

(4) Sax, N.I., "Dangerous Properties of Industrial Materials", Reinhold Publishing Corp., 1957

3.1.4.3 Controls

Oven controls are mounted in a replaceable module at the top of the oven. The input power line enters through a quick-disconnect at the back. Controls consist of a temperature control unit, an interval timer and status indicators including air temperature.

3.1.4.3.1 Temperature Control Unit (T.C.U.)

The T.C.U. is an hermetically sealed silicone controlled rectifier (SCR) type with ON-OFF action rather than proportioning to prevent EMI problems. The AC powered controller is much lighter than a comparable DC unit. The temperature sensor is a resistance temperature detector (RTD) strung near the inlet to the blower where it is unaffected by the wall heater and does not interfere with installation and maintenance. The non-adjustable temperature set point is 180°F, and is held within 3-4 degrees. The wall heater area has been sized so that its temperature with blowers operating will not exceed 400°F and in general will operate at an average of about 300°F. However, to prevent accidental overheating resulting from blower failure, a thermostatic switch,sensing wall temperature will cut power on temperature rise above about 425°F. This switch would have a 200°F differential and so would not cause rapid cycling on temperature drop.

3.1.4.3.2 Timer

The interval timer controls the active heating period. A set point range of 90 minutes is adequate for the longest heating times considered. The set point is continuously adjustable within this range to allow for future variations but would be marked for three conditions as follows:

a) Mixed frozen and thermostabilized meal. Regardless of loading, this point would be marked at the longest heating time requirement, namely 80 min. The small savings in time for smaller food loads is probably not worth the complexity of variable settings based on food mix and number.

b) No frozen food, but some thermostabilized food. This marking would be based on the longest heating time for a full load of thermostabilized food, namely 40 minutes.

c) Rehydratable food only. This setting would be about 3-5 minutes and serves to warm those masses in contact with the food package.

Following the heating times outlined, the heater would be shut down and two fans only would continue operation. The operating fan power would approximately balance the heat leakage, and the oven now serves a holding function. The timer will then cut power to the fans after a two hour interval, unless the operator intervenes.

3.1.4.3.3 Status Indicators

a) Power. A lighted switch indicates power on.

b) Timer Dial. The dial serves to set heating time and indicates time remaining to heat, and holding time.

c) Food ready. When the oven power is cut by the timer, a Food Ready indicator is illuminated.

d) An overtemperature, or malfunction warning light will indicate electrical power problems.

e) Oven air temperature is indicated on a gauge with normal temperature range marked.

3.1.4.4 Performance

3.1.4.4.1 Heating Time

a) The baseline performance is calculated by assuming a conservative heat transfer coefficient, h, of 4 BTU/hr-Ft^2°F. Analysis shows that this lower limit can be assigned with a high degree of confidence. Values of 5 or perhaps 6 are possible with refinement of design and blower (See Appendix A, Volume II, for detailed calculations).

The heating calculation is based on finite difference techniques, the details of which are given in Appendix B. The calculation accounts for phase change

for frozen food. Heat enters the food package on all sides in proportion to the difference between the local food temperature and the oven air set point temperature. However, at the start of heating if this calculated heat input exceeds the available heater power, then the air temperature is reduced so that the heat input does not exceed the maximum available heat. Heating calculations were made for the high and the low values of thermal diffusivities (α) of frozen and thermostabilized food. Measured values for Skylab foods were used (5). For thermostabilized food, the extremes were: chili, α = .00606 ft^2/hr, and stewed tomatoes, α = .00540. For frozen food the extremes were filet mignon, α = .0418 frozen, .00631 thawed, and lobster newburg α = .0430 frozen, .00583 thawed.

The time to heat the frozen food controls the overall heating time for the 2 meals per day when both frozen and thermostabilized foods are prepared. Figure 3-12 shows heating curves for an oven loaded with 7 frozen foods and 14 thermostabilized foods for the extreme values of thermal diffusivities. The maximum oven power in this case is 500 watts. Based on the slowest heating food, the time to reach an average temperature of 150°F is approximately 73 minutes. At this time the thermostabilized food temperature may be 18°F higher. The faster heating frozen food reaches 150°F almost 10 minutes sooner than the slower.

(5) R.B. Bannerot, J.E., Cox, C.K. Chen and N.D. Heidelbaugh, "Thermal Preparation of Foods in Space Vehicle Environments", Aerospace Medicine, p. 263, March 1974

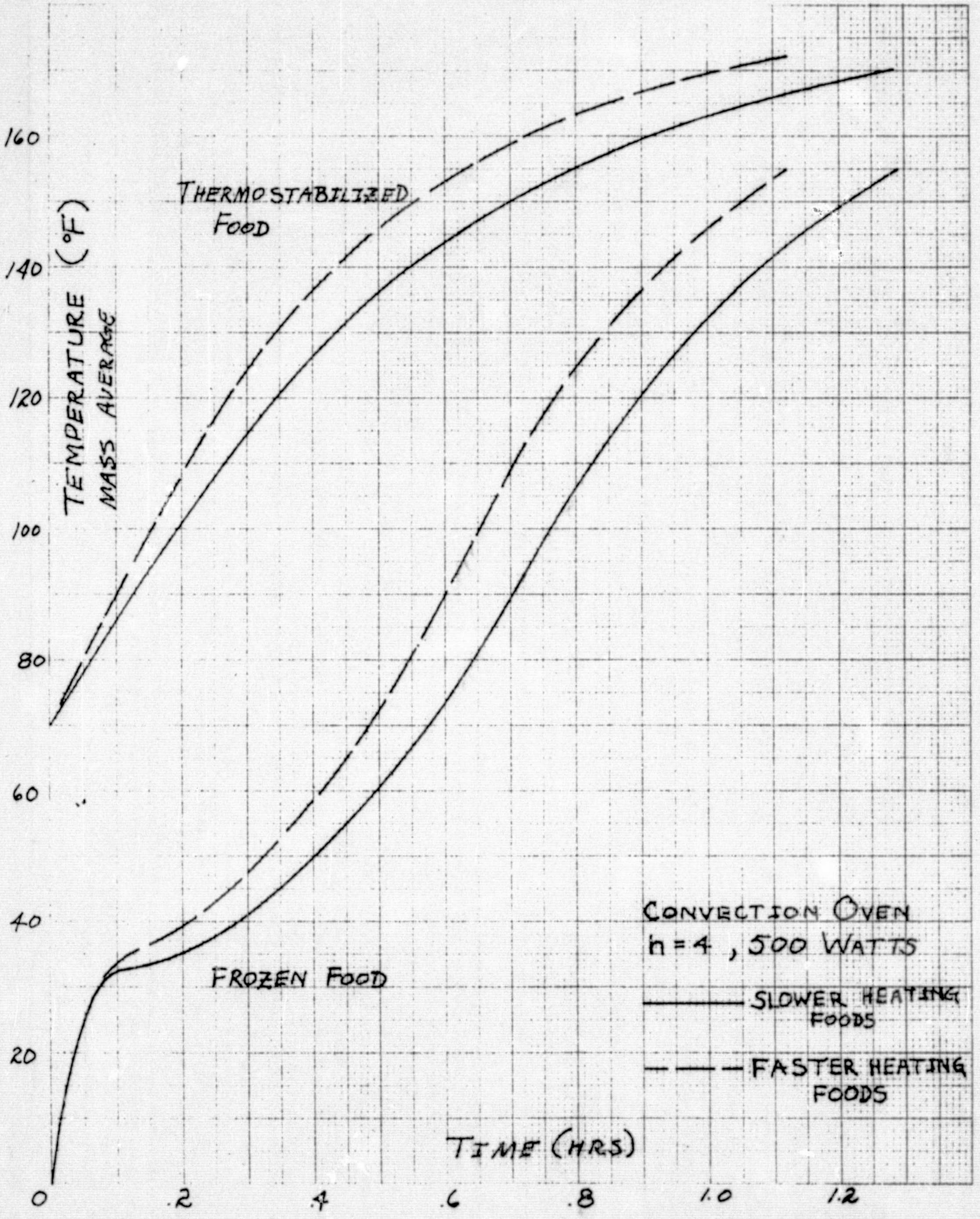


Figure 3-12. Convection Oven Heating Curves for Range of Food Types

Because heat is applied to all surfaces, the variation between the coldest point and the mass average is comparatively small. This is illustrated in Figure 3-13. At the time the frozen food mass average temperature is 150°F, the coldest part is 133°F. If the food were taken from the oven at this point, the cold spot temperature would continue to increase toward the average temperature. The heating calculations, the computer printouts of which are shown in Appendix B, were carried out up to a mass average temperature of 155°F. At this point heating ceased and an adiabatic boundary was assumed. The food average temperature remains the same but heat is redistributed. In the example just discussed when the average temperature reached 155°F, the cold spot temperature is 140°F. After five minutes it is at 145°F, and after 15 minutes it reaches 150°.

The time interval for the frozen food temperature to traverse the range 70°F - 140°F is 0.51 hours. The design guidelines had set a target 0.5 hours and has essentially been achieved.

b) Significant improvement can be made at higher values of heat transfer coefficients. A value for h of 5 or 6 is considered possible for the design. Figure 3-14 gives heating curves for the slower heating foods for values of h equal to 4, 5 and 6. At a final temperature of 150°F, the time savings over the baseline oven of h = 4, is 10 minutes for h = 5, and 17 minutes for h = 6. Note that the thermostabilized foods follow rather closely. This results from the fact that the oven is considered to have both frozen and thermostabilized food. With higher h the initial air temperatures are lower so that the corresponding decrease in ΔT offsets the higher h. If only thermostabilized food were in the oven, then the higher h would give a clear time advantage for heating thermostabilized food. At an h of 4 there is not a great distinction between an oven loading of all thermostabilized food or mixed frozen and thermostabilized, as illustrated in Figure 3-15. The heating time for an all thermostabilized meal not exceed 40 minutes.

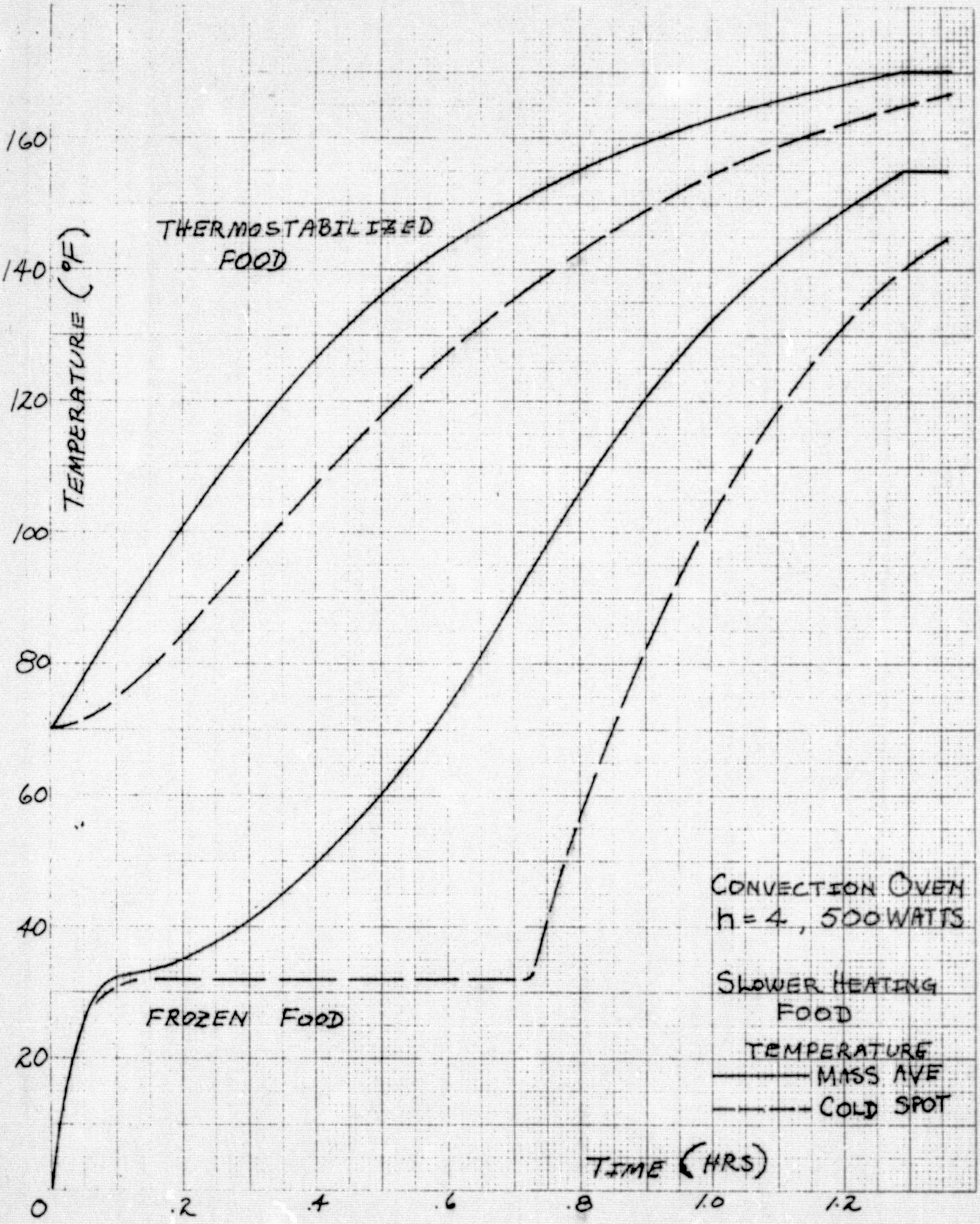


Figure 3-13. Comparison Heating Curves for the Cold Spot and the Mass Average

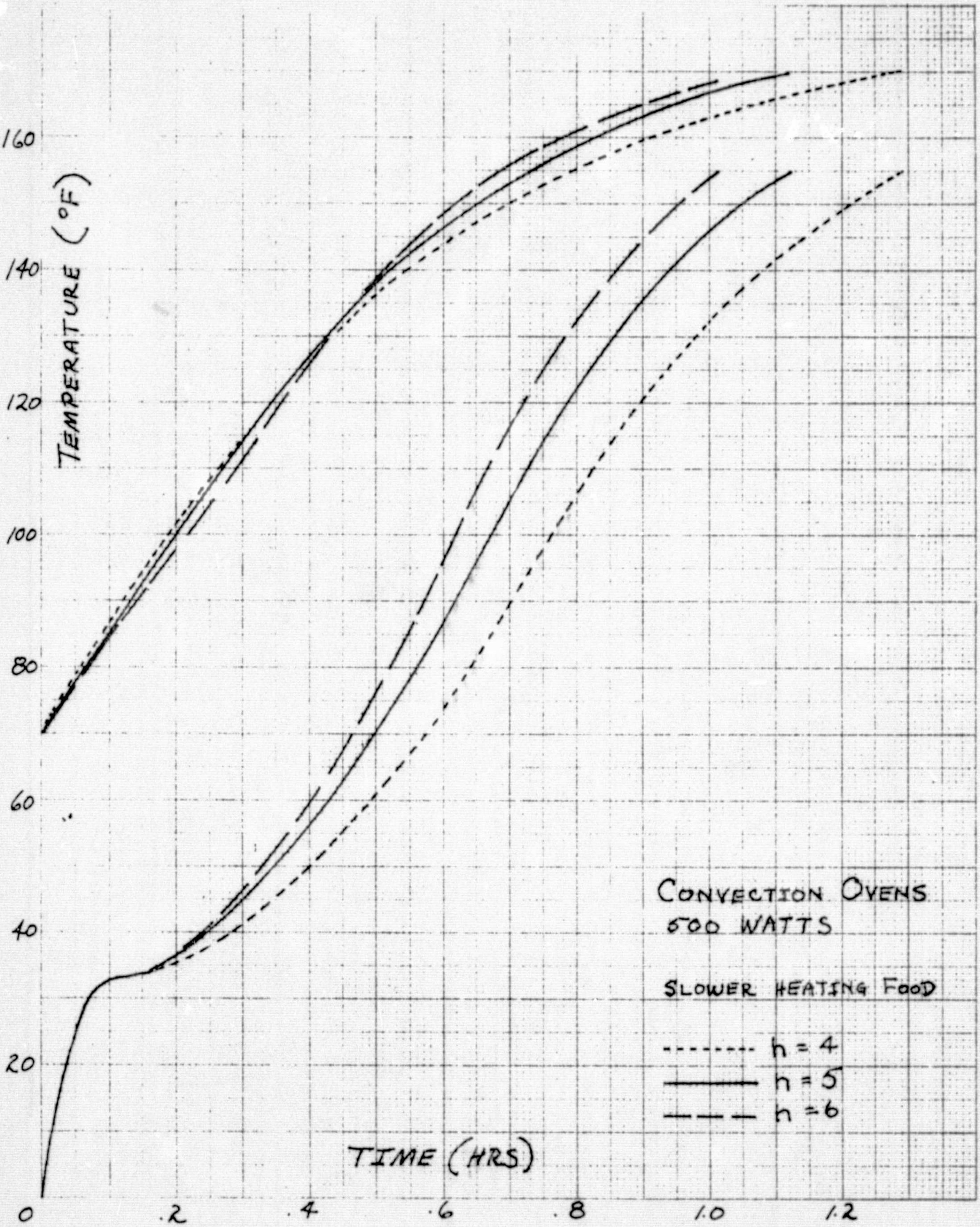


Figure 3-14. The Effect of Heat Transfer Coefficient on Heating Curves

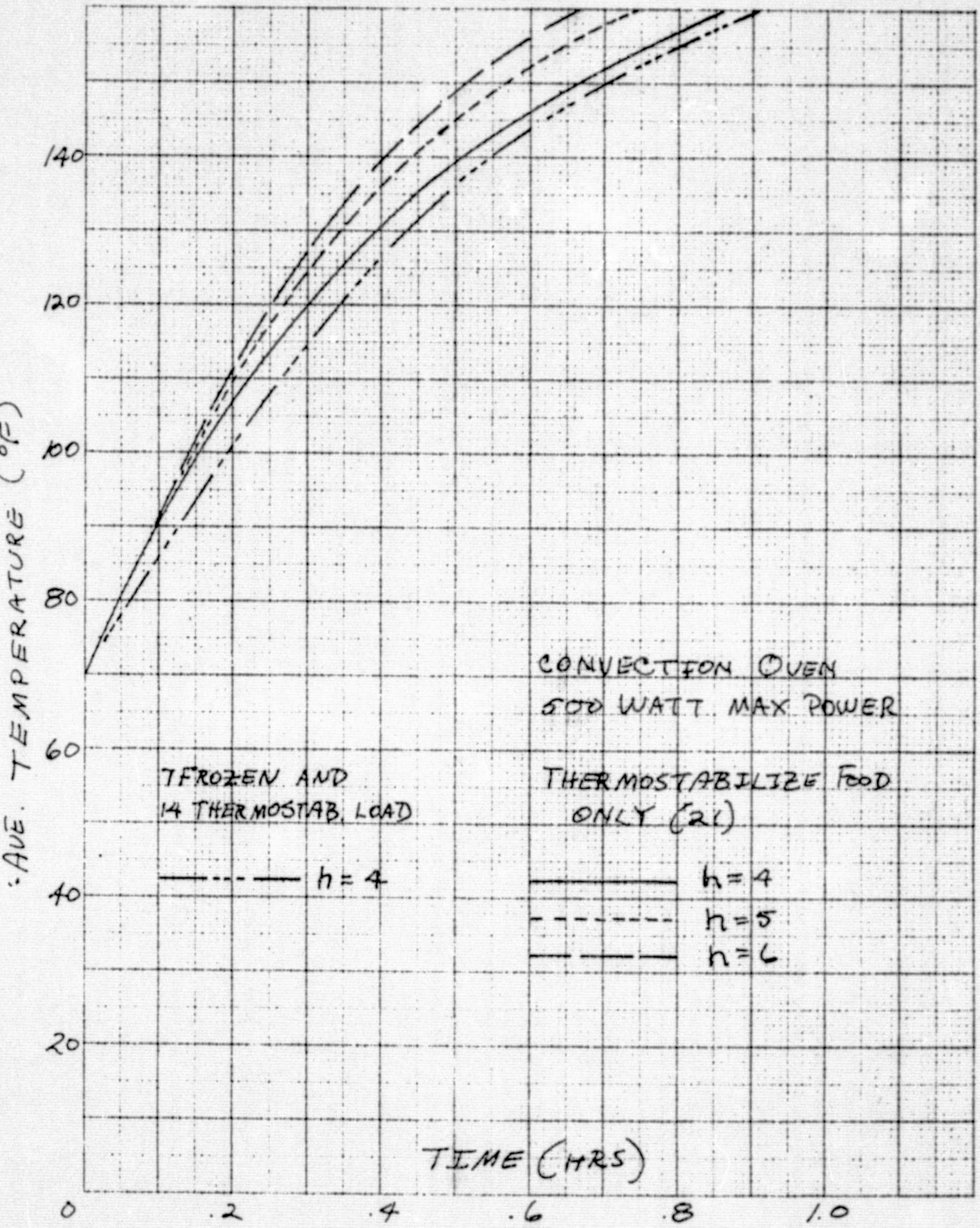


Figure 3-15. Thermostabilized Food Heating Curves for an Oven with Thermostabilized Food Only Compared to an Oven Load of Mixed Frozen and Thermostabilized Food

3.1.4.4.2 Power

This section establishes the justification for the use of 500 Watts as the maximum heating power. The analysis is based on an oven loading of 7 frozen and 14 thermostabilized food cans.

In the convection oven, the power input to an individual can, when the oven power is limited, depends on the number and surface temperature of other cans present. This power is

$$P_{can} = h \times Area \times \Delta T$$
$$= .07191\ h\ \Delta T \text{ Watts} = Ch\Delta T$$

where ΔT is the difference between the average surface temperature and air temperature. The total oven power is therefore:

$$P_{oven} = 7Ch\ (Tg - Tf) + 14\ Ch\ (Tg - T_t)$$

where Tg is air temperature

Tf is average frozen can surface temperature

T_t is average thermostabilized surface temperature

At the start of heating the air temperature is less than the 180°F set point because of the limit on oven power.

At time = 0 the power per frozen can is:

$$P_{can\ (f)} = \frac{(P_{oven} + 980\ Ch)}{21}$$

The thermostabilized can power is

$$P_{can\ (t)} = \frac{(P_{oven} + 980\ Ch)}{21\ C} - 70\ Ch$$

Thus for a 500 Watt oven and h = 4, the power per frozen can is 37.23 Watts and for thermostabilized can 17.1 Watts. By contrast in a 500 Watt conduction oven the power to any can is 23.8 Watts at time = 0. As time goes on, the maximum power input to a can

in a convection oven depends on the current surface temperature of the other cans with which it shares the available heat. Consequently, the time-temperature history is a function of the total oven loading.

If we take an oven composition of the slower heating foods and compute the heating curves for a range of power, we can assess the effectiveness of increasing power on shortening of heating time. Figure 3-16 plots the heating curves for frozen foods in an oven with maximum powers of 300, 500, and 700 Watts. It is apparent that increasing power at the upper range is less effective than the lower range in shortening heating time. This effect is shown clearly in Figure 3-17, where the time to heat the frozen food from 0 to 155°F is shown as a function of oven power.

If can input power is plotted as a function of time, Figure 3-18, maximum power is seen to be used at the start as the oven air warms to the set point. At this point the heaters begin to cycle and the time average power decreases continually and would approach the oven leakage rate. At low oven power levels, the time at peak power usage is long and increasing the power level results in marked decrease in heating time. This gives the steep portion of the slope in Figure 3-17 (Ref.). At high oven power levels, the time at maximum can input power level decreases as shown in Figure 3.19 and further increases in oven power are not very effective in reducing heating time since the heater is soon cycling. This corresponds to the flat portion of the curve in Figure 3-17 (Ref.). The choice of maximum oven power would be the point where the heating time requirement to traverse the temperature range 70-140°F is met, and where additional power does not justify the additional reduction in total heating time. For an h of 4, the break in the curve at about 500 watts, as shown in Figure 3-17 (Ref.), where the slope begins to decrease rapidly seems a reasonable choice.

3.1.4.4.3 Energy

The energy required to heat an oven load of 7 frozen and 14 thermostabilized foods of the slower heating type to the point where the frozen food average temperature is 155°F

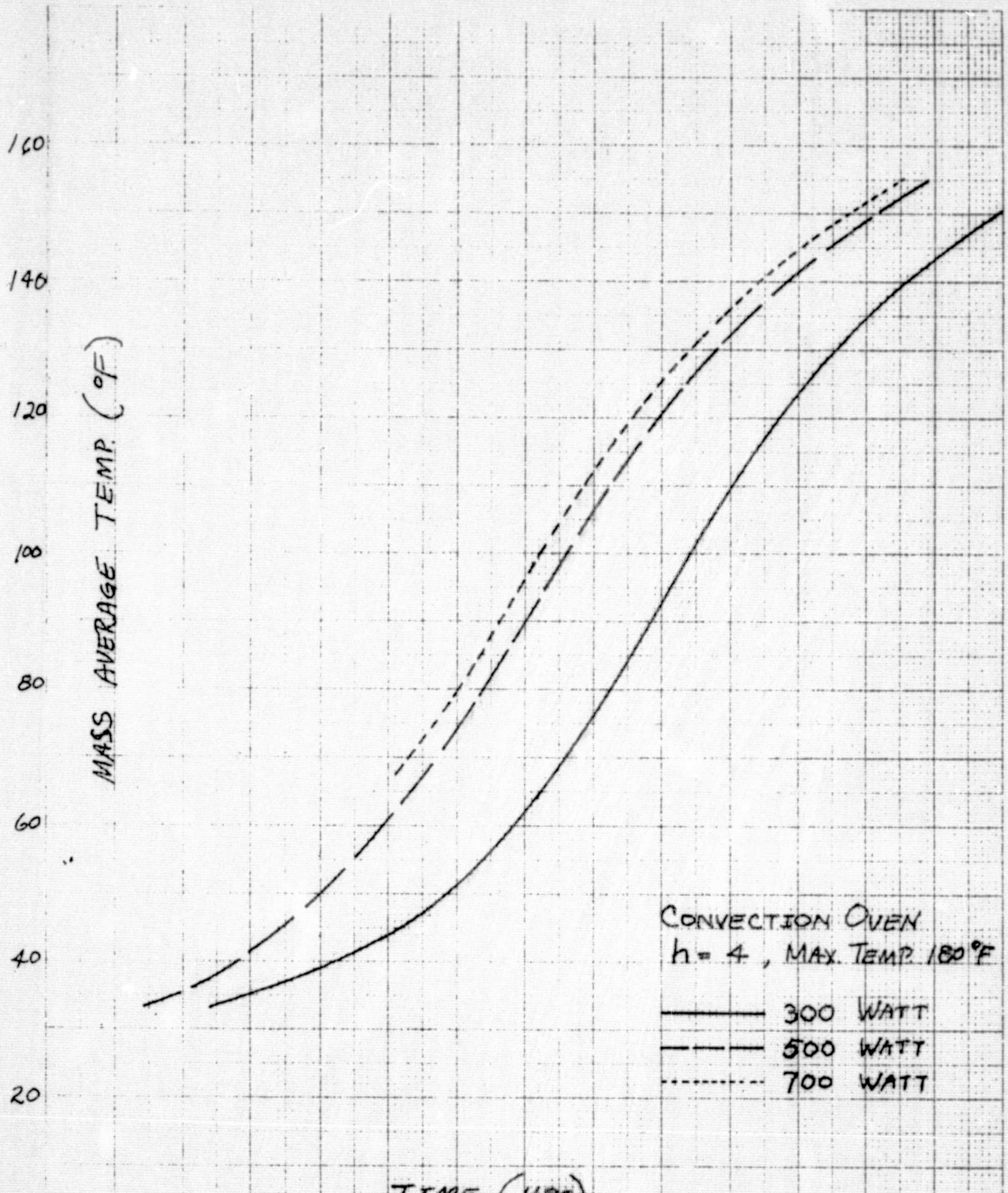


Figure 3-16. The Effect of Maximum Oven Power on the Heating Curve

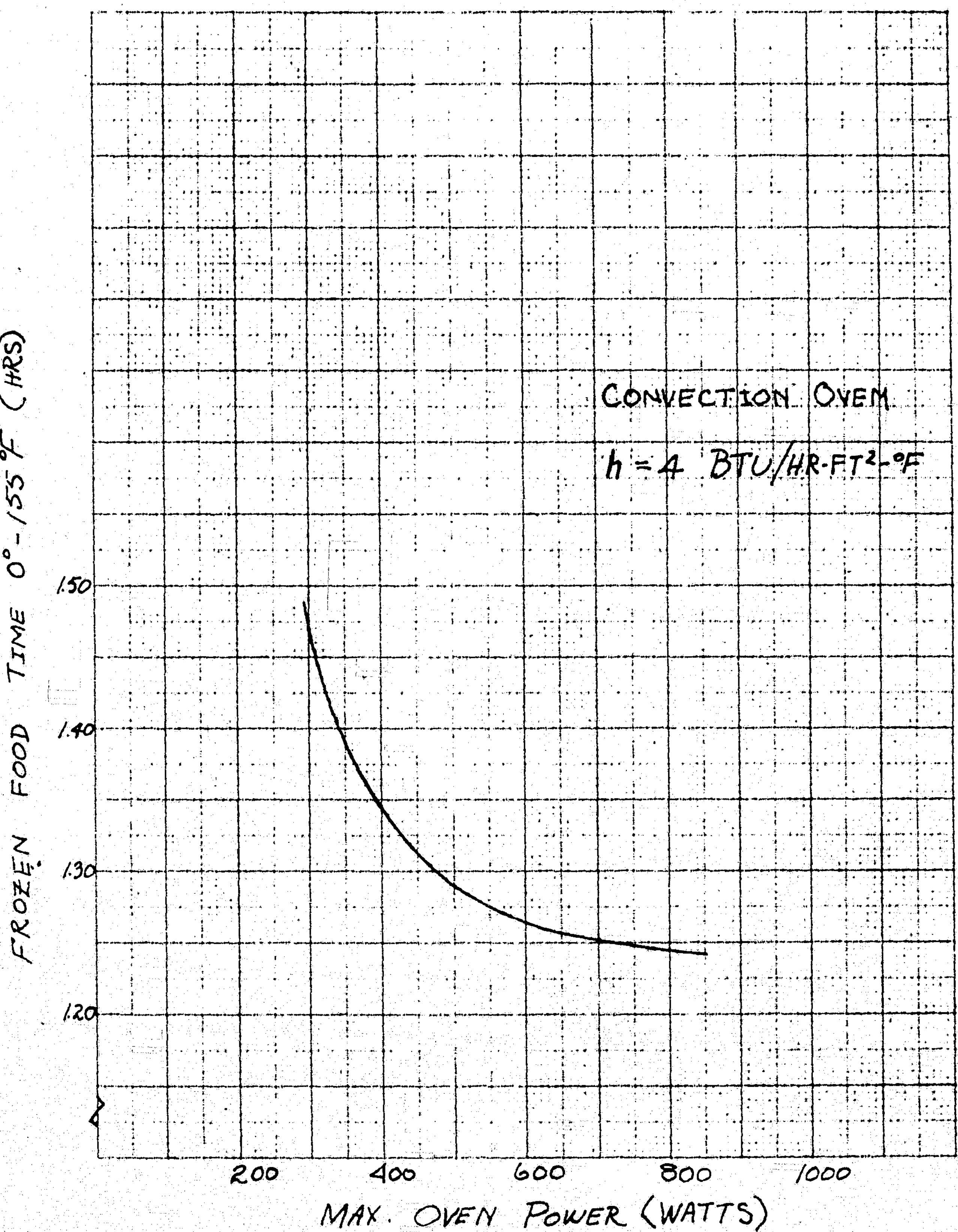


Figure 3-17. The Effect of Maximum Oven Power on the Time to Heat Frozen Food from 0° to 155°F

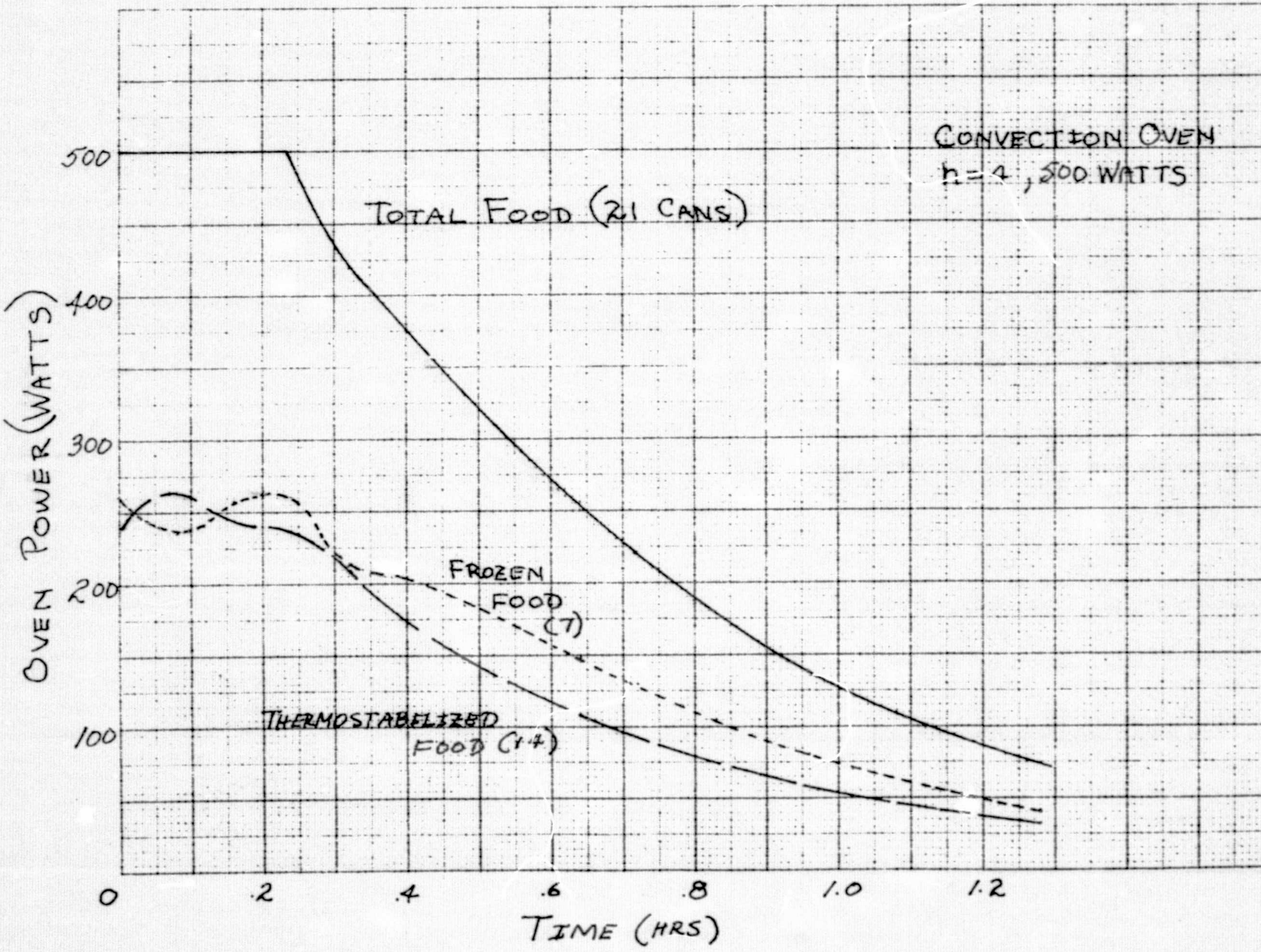


Figure 3-18. Time Average Oven Power Usage with Time

FAIRCHILD REPUBLIC COMPANY

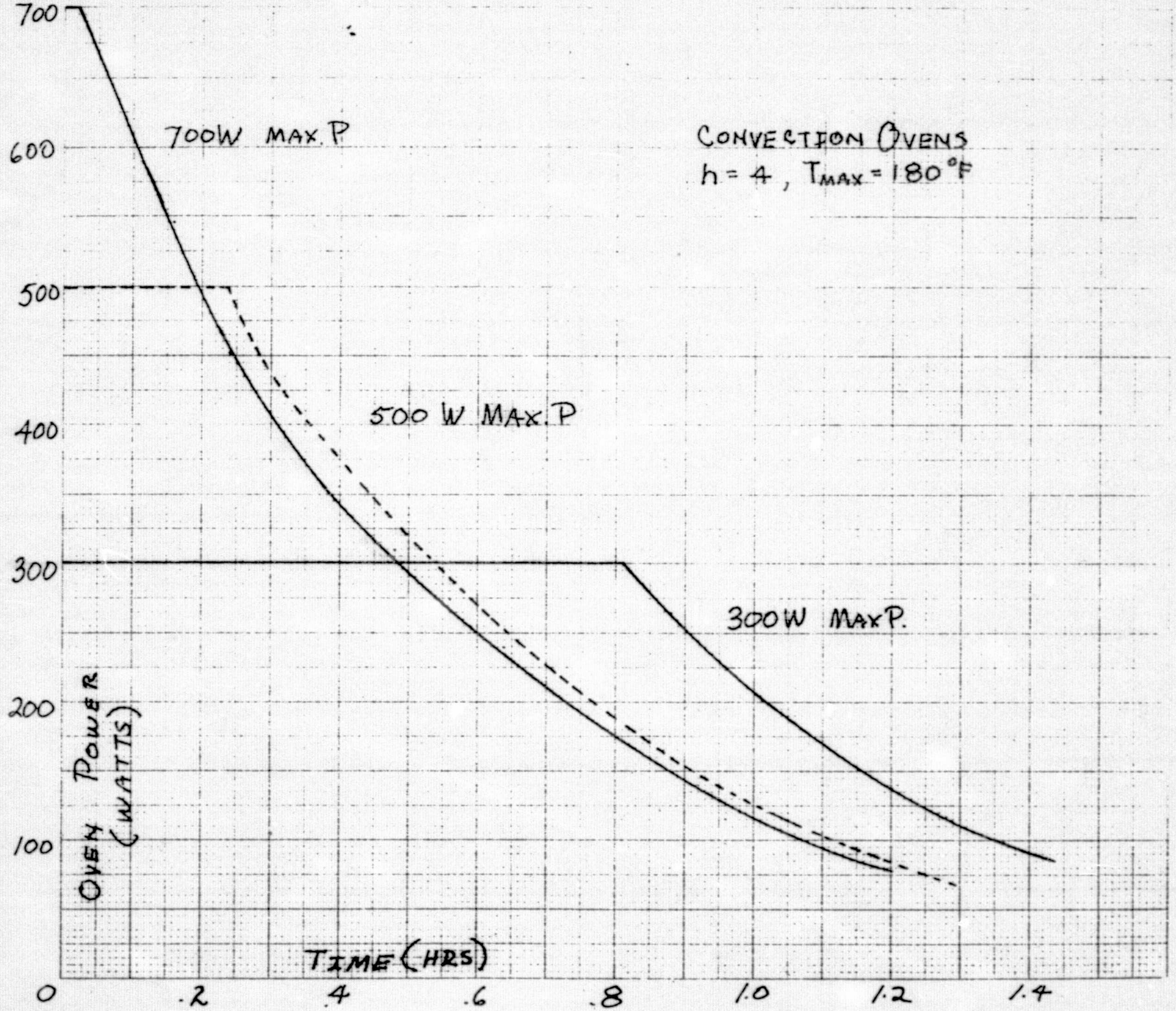


Figure 3-19. Comparison of Oven Power Usage for Various Maximum Oven Powers

is 356 watt-hr. During the 1.29 hours required for heating, heat is also lost through the oven walls. If the calculated steady state heat leakage of almost 60 watts is pessimistically assumed to apply at time = 0, then the heat loss is 77 watt-hr.

After the food is heated the oven cycles into a holding mode by simply operating two fans at a power of 70 watts, which is a little more than the leakage loss. The energy consumption at various times is:

	At Completion of Heating	After 1 Hr. Holding	After 2 Hrs. Holding
Energy Consumption (W - hr.)	433	503	573

If the meal consists of 21 thermostabilized foods, then the energy requirement including losses is:

	At Completion of Heating to 150°F	After 1 Hr. Holding	After 2 Hrs. Holding
Energy Consumption (W - hr.)	242	312	382

3.1.4.5 Weight

The weight of the convection oven and its components is estimated in Table 3-1. For the purposes of later comparison with other oven concepts, the weight of the tray insert as well as an item called "delta tray" are included. This latter item attempts to account for the differences in the tray configuration resulting from the tray insert design. In the case of the baseline oven and the conduction oven, the insert is essentially a complete subsystem in itself and need only be attached to the serving tray. In the convection oven, the insert is designed to minimize obstruction of the hot air current and simply supports the food package as shown in Figure 3-10 (Ref.). The serving tray would therefore have to supply additional mounting structure to accept this insert and food package. This delta tray mass was approximated by subtracting the tray insert mass from the mass of the baseline oven.

TABLE 3-1. CONVECTION OVEN WEIGHT

Outer Structural Shell	11.17 pounds
Inner Shell	2.68
Insulation	1.14
Heater	0.46
Controls	4.03
Hardware	0.26
Blowers (3)	1.09
	20.83
Inserts (7)	.91
Delta Tray (7)	4.28
	5.19
Total Weight	26.02 pounds

3.1.4.6 Volume

The volume of the convection oven is 1735 cubic inches.

Perhaps a more meaningful statistic is the front face area, since the depth beyond any component is of limited use due to the galley configuration. The convection oven front face is 8.12 inches wide and 15.5 inches high for an area of 126 square inches.

3.2 Conduction Oven

The conduction oven is essentially based on the individual food can with its own heater and temperature control. The unit conduction heater is similar to that employed in Skylab. The options involve the methods of grouping the individual heaters to form a heating tray dedicated to one crewman, or a fixed oven in the galley.

a) Fixed oven. This concept has clusters of heaters arrayed at a fixed part of the galley. Cans are inserted for heating and transferred to the dining tray after heating. Figures 3-20, 3-21, and 3-22 are examples of this approach.

b) Heating Trays. An insert, detachable from the dining tray and containing three heaters and controls, can be loaded with food packages and placed in an insulated chamber in the galley which provides a power outlet and storage place for the tray. To accommodate any mix of square or round food packages, individual heater elements, either round or square, are connected to the food tray insert shell to make up the complete insert. This approach, illustrated in Figure 2-3 (Ref.), avoids the necessity of handling individual hot cans, but does require 42 holders to handle the range of food mixes and involves frequent making of electrical connections for conversion.

3.2.1 Conduction Oven Study Selection

The wired tray insert concept shown in Figure 2-3 (Ref.) was chosen. Individual heater sleeves complete with temperature control would be connected to the insert and the insert placed in an oven for power. The wall temperature for round cans would be maintained at 180°F, and for square packages 150°F. An inventory of 21 of each sleeve type is required.

3.2.2 Initial Design Evaluation

The conduction oven initial design shown in Figure 2-3 (Ref.) was developed from the necessity to accommodate both a round can for frozen and thermostabilized foods, and a square

CONDUCTION OVEN

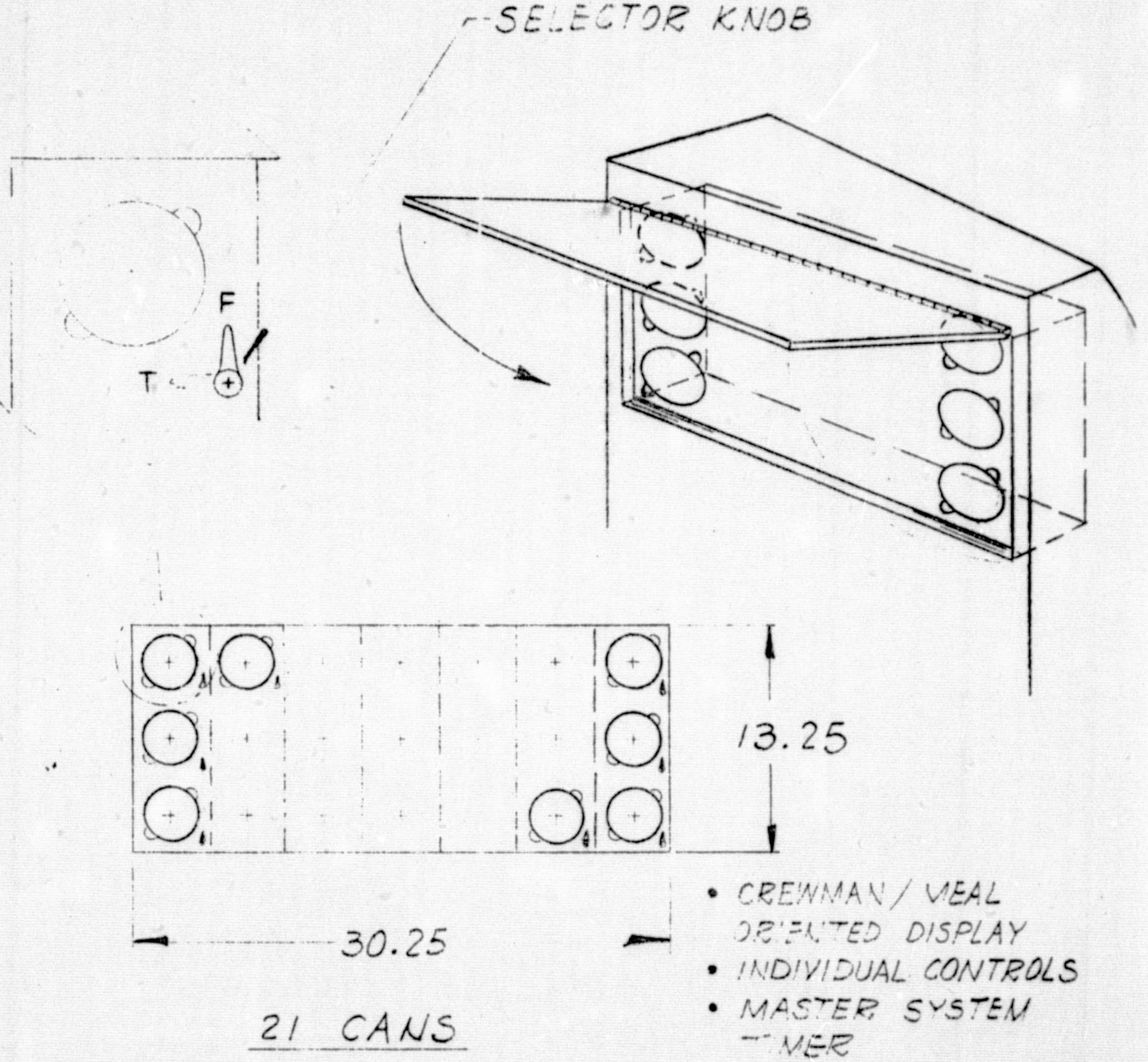


Figure 3-20. Conduction Heater Array Placed in Shallow Portion of Galley.

CONDUCTION OVEN

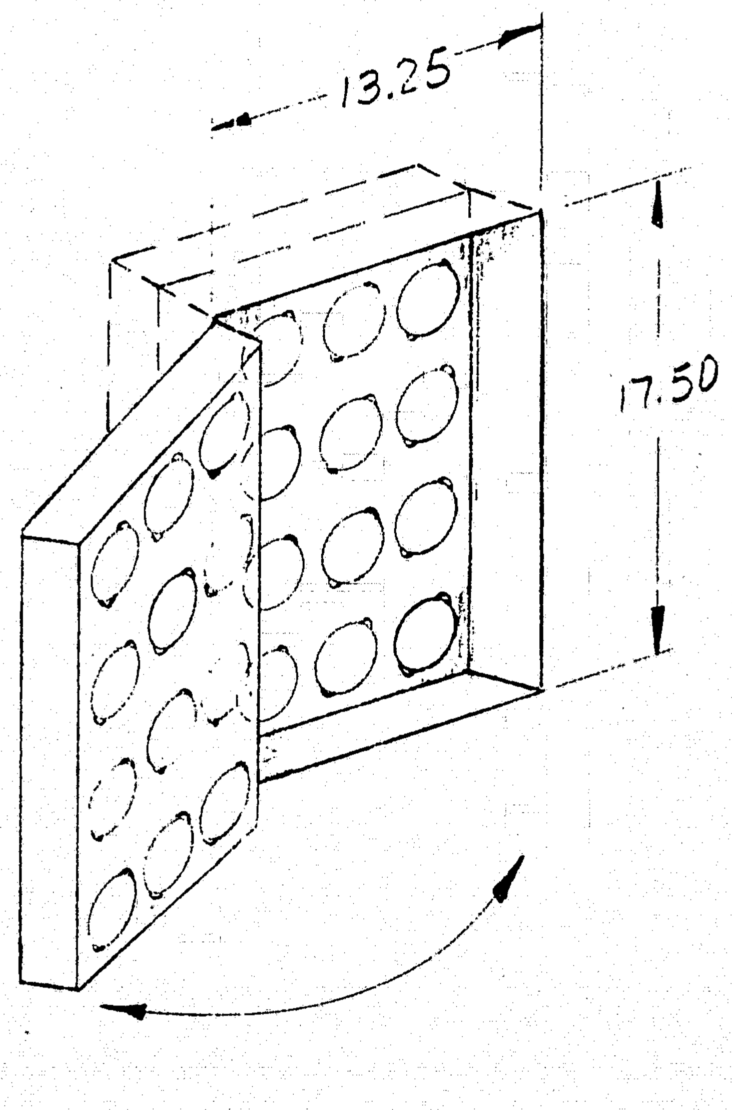


Figure 3-21 Compact Heater Array, With Half of Heater in Door

CONDUCTION OVEN

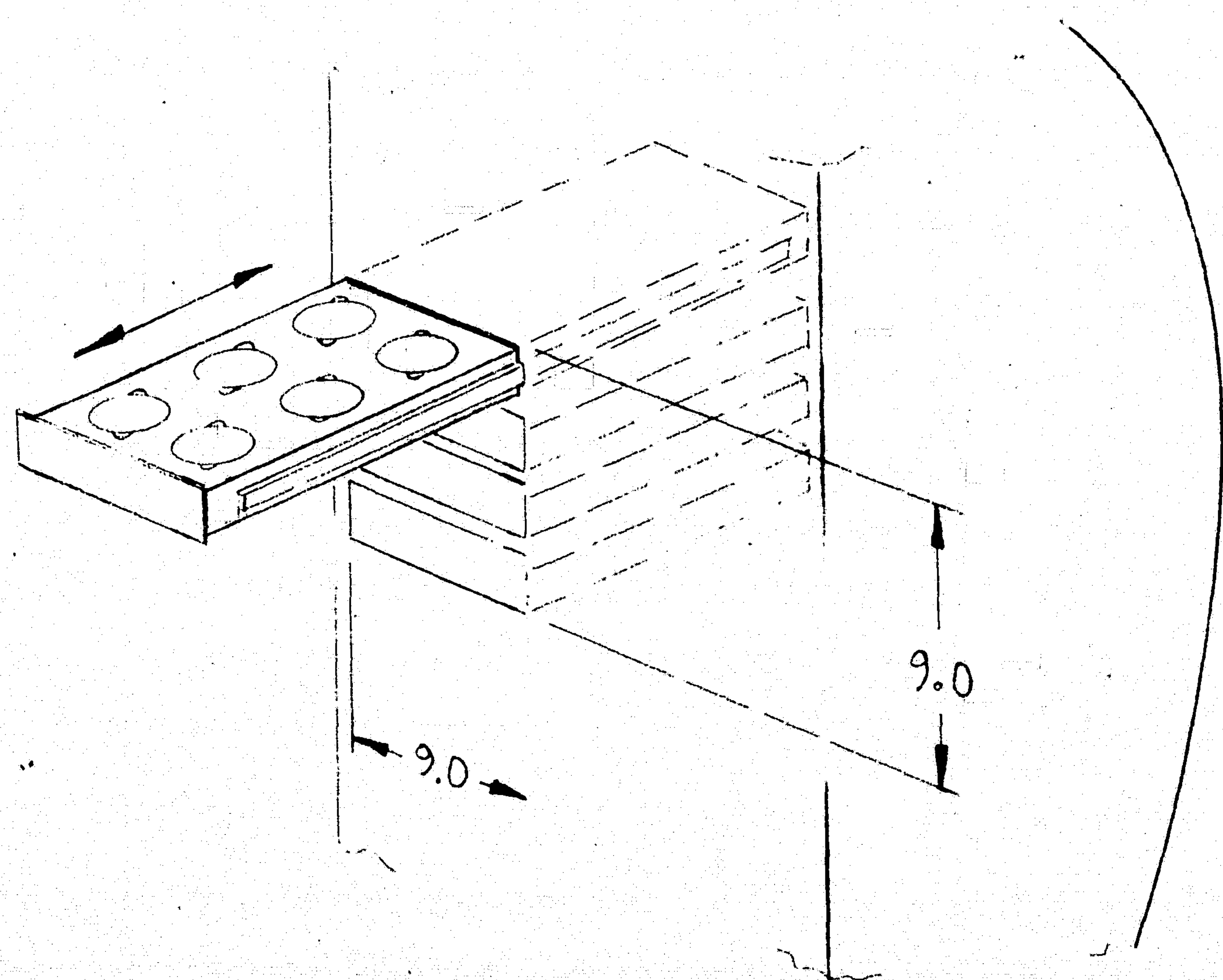


Figure 3-22. Compact Heater Array Arranged in Four Drawers

rehydratable food package. The necessity to provide 21 of each type of removable heater sleeves imposes severe penalties in operational complexity and adds weight and storage requirements for the unused heater sleeves. To minimize the number of wires in the connector from tray insert to heater sleeve, the temperature controller would be contained in the replaceable sleeve. Since the temperature sensor is a resistance wire,this also eliminates the possibility of contact resistance changes leading to sensor error. However, even with the minimum number of wires for power leads, the routine use of connectors was not considered desirable from the viewpoint of keeping out debris from cleaning and handling, and for reliability. Consequently, alternative designs to interchangeable heater sleeves were sought.

3.2.3 Alternate Approaches

The simplest approach is to design the tray insert with three integral heaters as flat plates at the bottom of the insert. This would heat the bottom surface of the food package only and consequently require longer heating times. Two methods of reducing heating times by heating the sides of the food package were considered.

In the first concept, the heater surface would extend beyond the area of the bottom of the can. A metallic band would be placed around the round can, make contact with the heater at the bottom of the insert and thus conduct heat to the can sides. While this avoids the connector problems it is again a weight penalty and an operational complexity.

The second alternative eliminates the conduction band and extends the heater partially up the sides of the can as described in section, 3.2.4.

3.2.4 Final Conduction Oven Design

The difference in package height between the 401 x 105 can and the 4" x 4" x 1.03" rehydratable package is 0.283 inches. If the square rehydratable package were allowed to extend somewhat above the round can when placed in the tray insert, a significant portion of the sides of the can could contact the fixed heater. Figure 3-23 shows the design finally chosen in which the lower one-half inch of the can is heated, and the rehydratable package

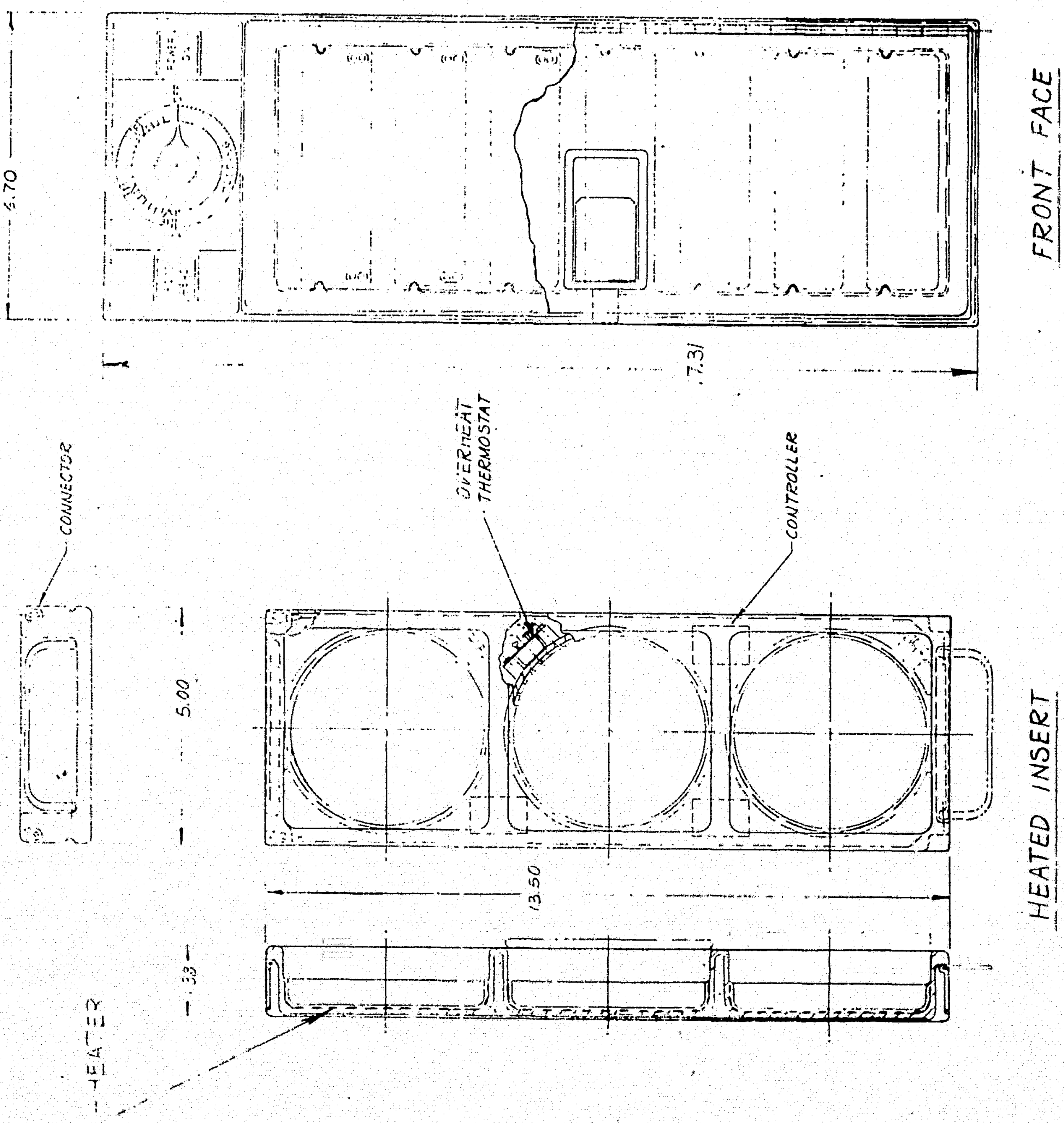


Figure 3-23a Conduction Oven and Tray Insert

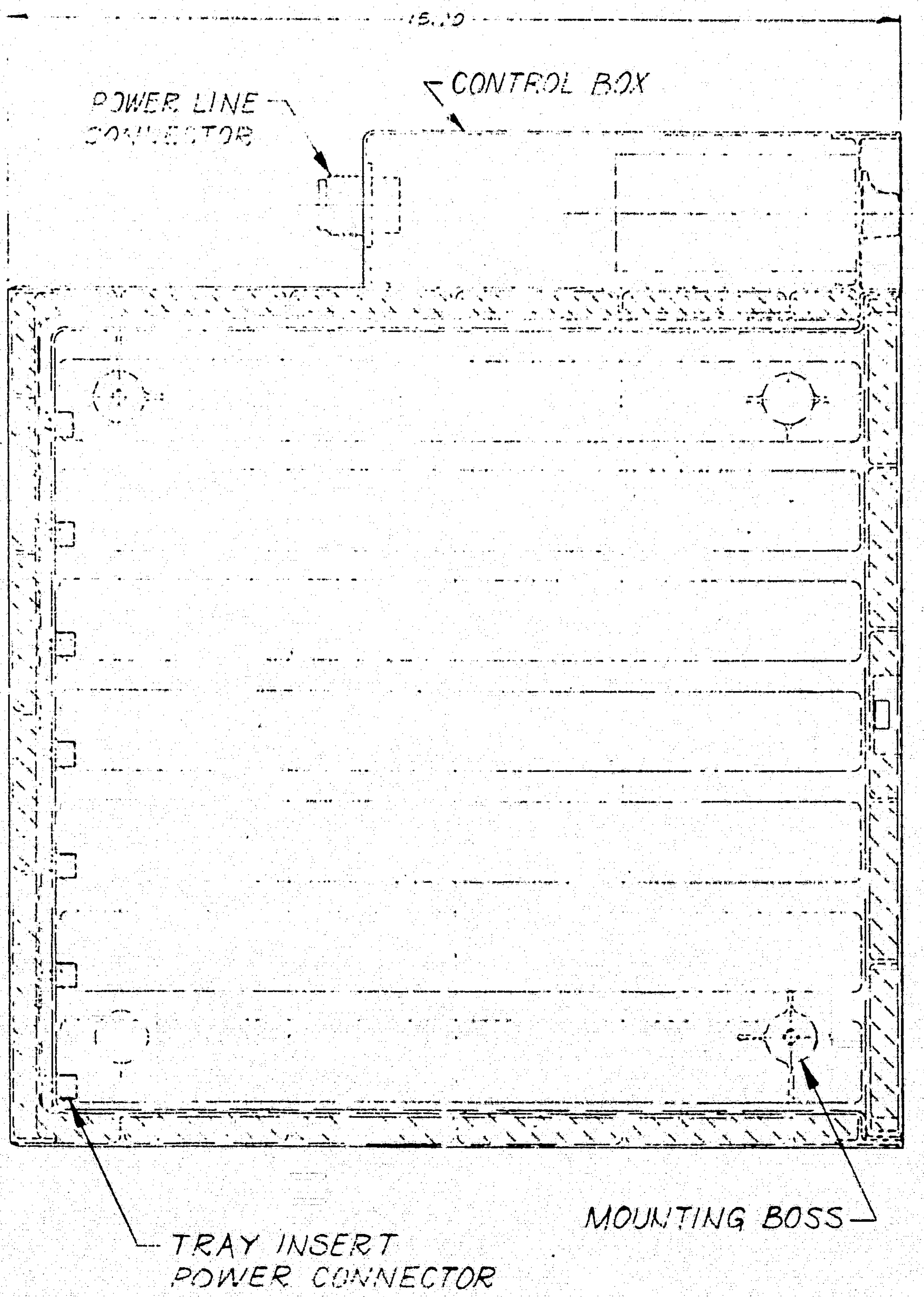


Figure 3-23b Conduction Oven, Side View

extends just .218 inch above the can. The insert has three fixed heaters approximately 3-3/4" diameter and 1/2" high. Above the heater the insert has a square opening 4" x 4" and 5/8" high. Three controllers are located in the base of the insert. Power lines to the heater are located in a connector at one end of the insert. The sides of the insert are grooved for insertion on guides into an oven cavity shown in Figure 3-23a. When fully inserted the insert connector engages power leads in the oven.

The oven provides insulation to limit heat loss and also prevents convection loss to the cabin.

The holding function for rehydratable food is accomplished by resistance heaters in the walls of the oven to hold the wall temperature at 150°F and prevent heat leakage from the food.

3.2.4.1 Heater Design

The heater is similar to the Skylab conduction heater. A teflon insulated resistance heater is shaped to the 401 can contour. The semi-flexible heater is slightly deformed by the can on insertion, forming a tight fit with good thermal contact. A resistance temperature detector in the heater is used to control heater temperature at 180°F and thus is adequately derated. Warm-up time is about two minutes.

3.2.4.2 Controls

Each heater has its own temperature controller to hold the surface temperature at 180°F. The controller is an hermetically sealed SCR type with ON-OFF action to prevent EMI problems. The controller and heater are AC powered to minimize weight and size. The temperature set point is non-adjustable and temperature is held within 3-4 degrees. The controllers, with dimensions of 1-1/8" x 1" x 5/8" are mounted in the base of the tray insert. To prevent overheating in the event of controller failure, a thermostatic switch monitors heater temperature and cuts power at 200°F. The switch differential is large enough to prevent recycling as the heater cools.

3.2.4.3 Performance

3.2.4.3.1 Heating Time

3.2.4.3.1.1 Removable Heater Sleeve

Rather than attempt to heat the cans from all sides, the heating approach was to utilize as much of the side walls as possible and the can bottom. In order to provide finger holes for removing the cans approximately 80% of the side and bottom may be heated. Heating calculations (see Appendix B for details) were based on maintaining the heater surface at 180°F with the limitation that the input power not exceed the heater rating. Figure 3-24 shows heating curves for the slower heating foods at a total oven power comparable to the convection oven, 500 watts, and also at 1050 watts (50 watts per can) which approximates Skylab heating power.

At 500 watts oven power the heating time for the frozen food exceeds the convection oven time. To reach a mass average temperature of 155°F required 1.38 hours compared to 1.28 hours for the convection oven. The thermostabilized food on the other hand requires only 0.52 hours to reach 155°F compared to 0.80 hours in the convection oven. In the conduction oven each heater has a peak power of 23.81 watts for a 500 watt oven power. In the convection oven the frozen food power is higher because of the greater ΔT and is 37.2 watts per can as opposed to 17.1 watts for thermostabilized food.

The 1050 watt oven shows a significant improvement in performance, reducing the frozen food heating time to 155°F by 0.42 hours.

A characteristic of the temperature distribution for conduction heating from the bottom and sides only is the rather wide difference between the average temperature and the cold spot temperature. Figure 3-25 shows the average temperature and the cold spot temperature for ovens of 500 to 2100 watts total power. The average temperature has reached approximately 150°F before the cold spot has completely thawed. The active heating was carried out to an average temperature of 155°F at the boundary then taken as adiabatic. The cold spot continues to rapidly increase in temperature. For the food to be nearly uniformly hot, it would have to either be thoroughly stirred, if possible, or else be allowed to sit for about 15 minutes.

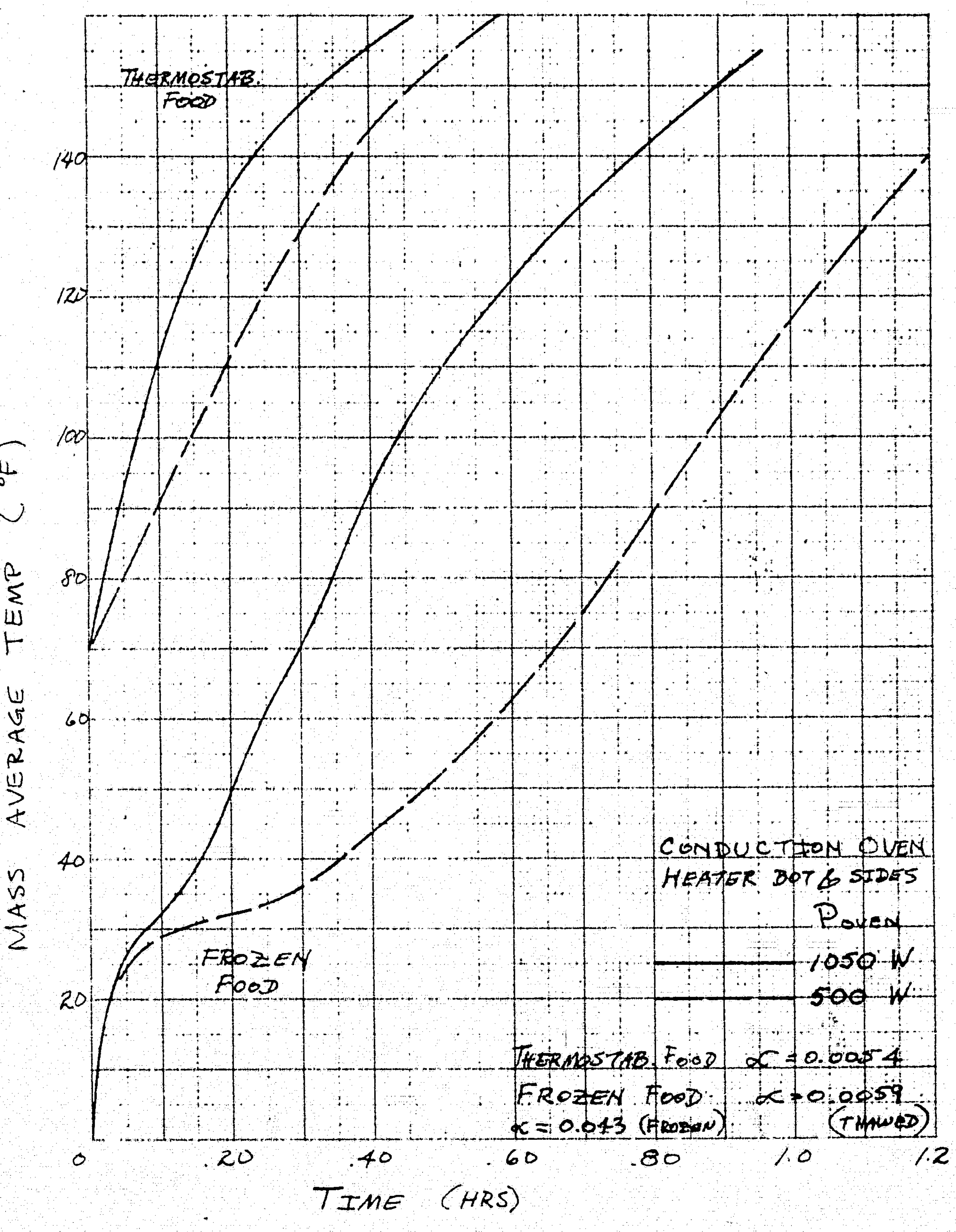


Figure 3-24. Conduction Oven Heating Curves for 500 and 1050W Maximum Oven Power

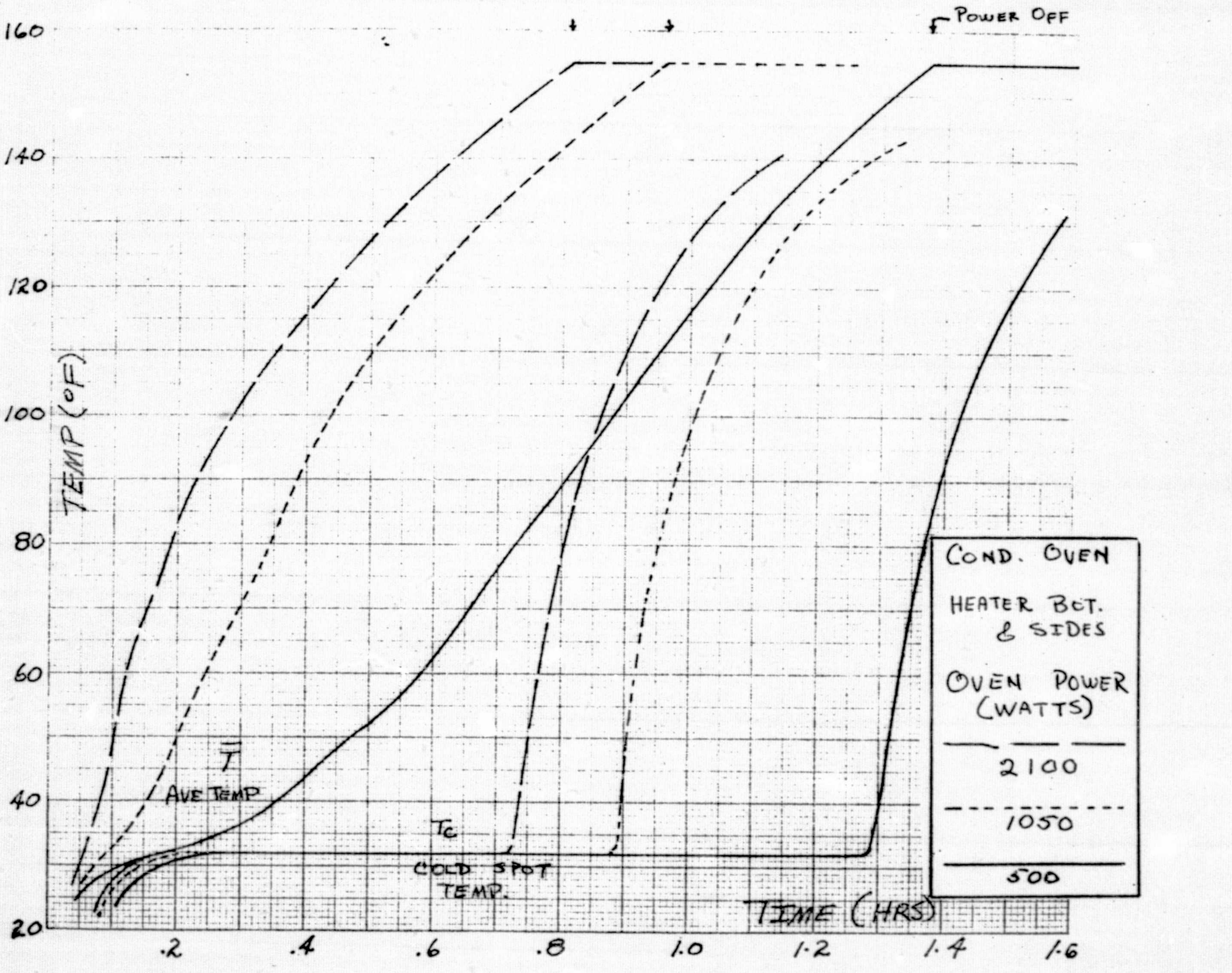


Figure 3-25. Comparison Heating Curves for the Cold Spot and the Mass Average

3.2.4.3.1.2 Fixed Heater

The cost in heating time in heating only the bottom one-half inch of the can is shown in Figure 3-26. The heating curve for a bottom heater only is also shown. The heating time from 0 - 155°F has increased by 0.38 hours but still is only about .05 hours longer than the convection oven at 500 watts total. The temperature distribution is more uniform with the longer heating time so that when the average temperature has reached 150°F, the cold spot is 120°F. Figure 3-27 shows the heating curves for the range of food types, and in Figure 3-28 the average temperature of the frozen foods is compared to the cold spot temperature.

3.2.4.3.2 Power

3.2.4.3.2.1 Heater, Bottom and Sides

The maximum desirable operating heater power may be determined in the same manner as for convection ovens. For the conduction heater, however, there is no interaction between cans, and in effect we have 21 small ovens. The heating time for frozen food from 0-155°F, as a function of maximum heater power is shown in Figure 3-29. By the same reasoning as used in the convection oven evaluation, the choice for the maximum operating power would be approximately 50 watts per can. Figure 3-30 shows the power utilization with time for an oven power of 500 watts. The broad max power usage shows that performance can be improved with higher max. power. The decreased usage of maximum power for the 1050 Watt oven (Fig. 3-31) indicates this power level is close to optimum. The power for the conduction oven is thus approximately twice as high as for the convection oven.

3.2.4.3.2.2 Fixed Heater

The performance for the fixed heater system is similar to the interchangeable, full side heater. Figure 3-32 gives the heating curve at power levels between 30 and 80 w/can. The time to heat frozen food from 0-155°F is shown in Figure 3-33. The power utilization with time for the 50 W/can oven is given in Figure 3-34.

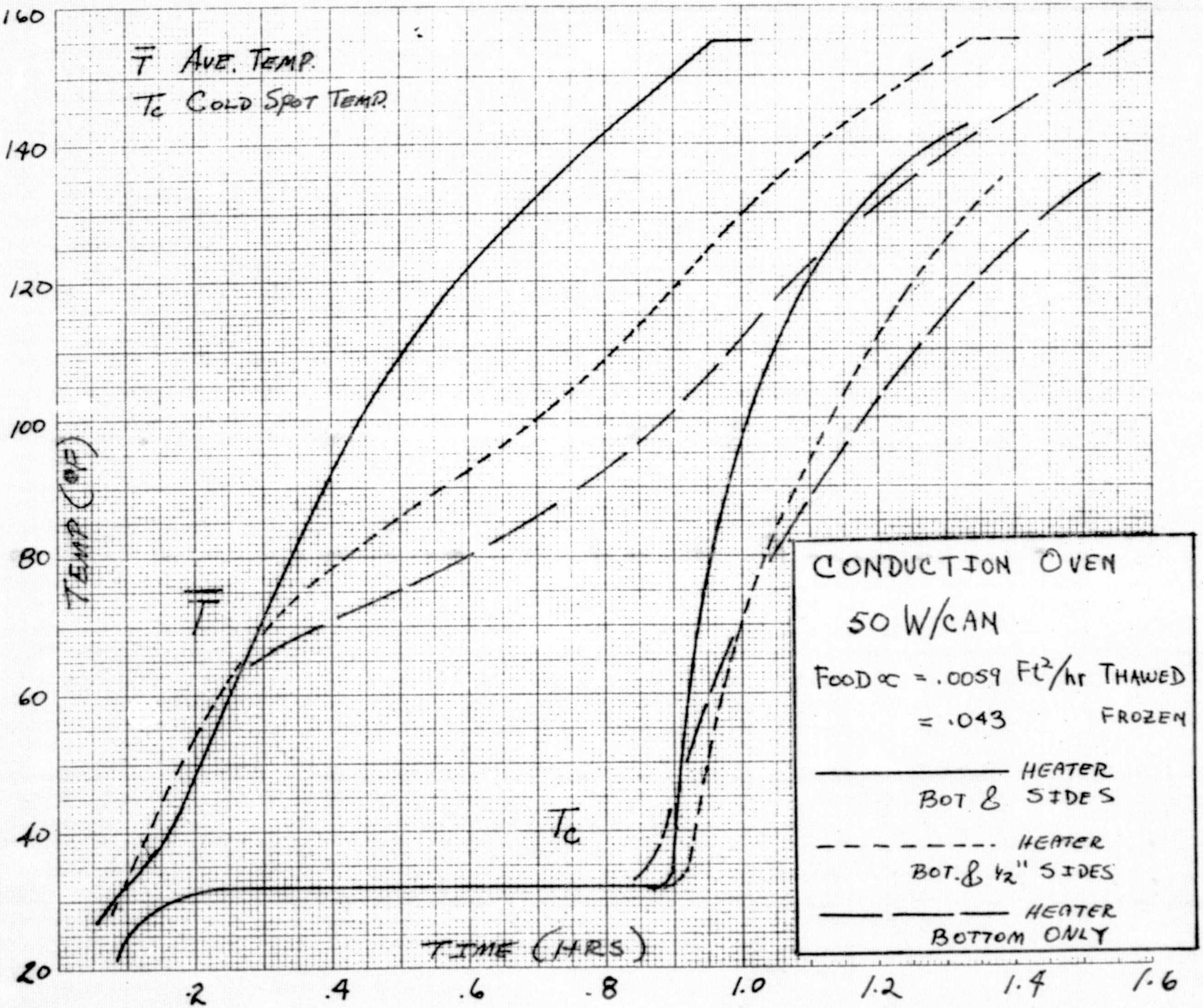


Figure 3-26. The Effect of Heated Area on the Frozen Food Heating Curve

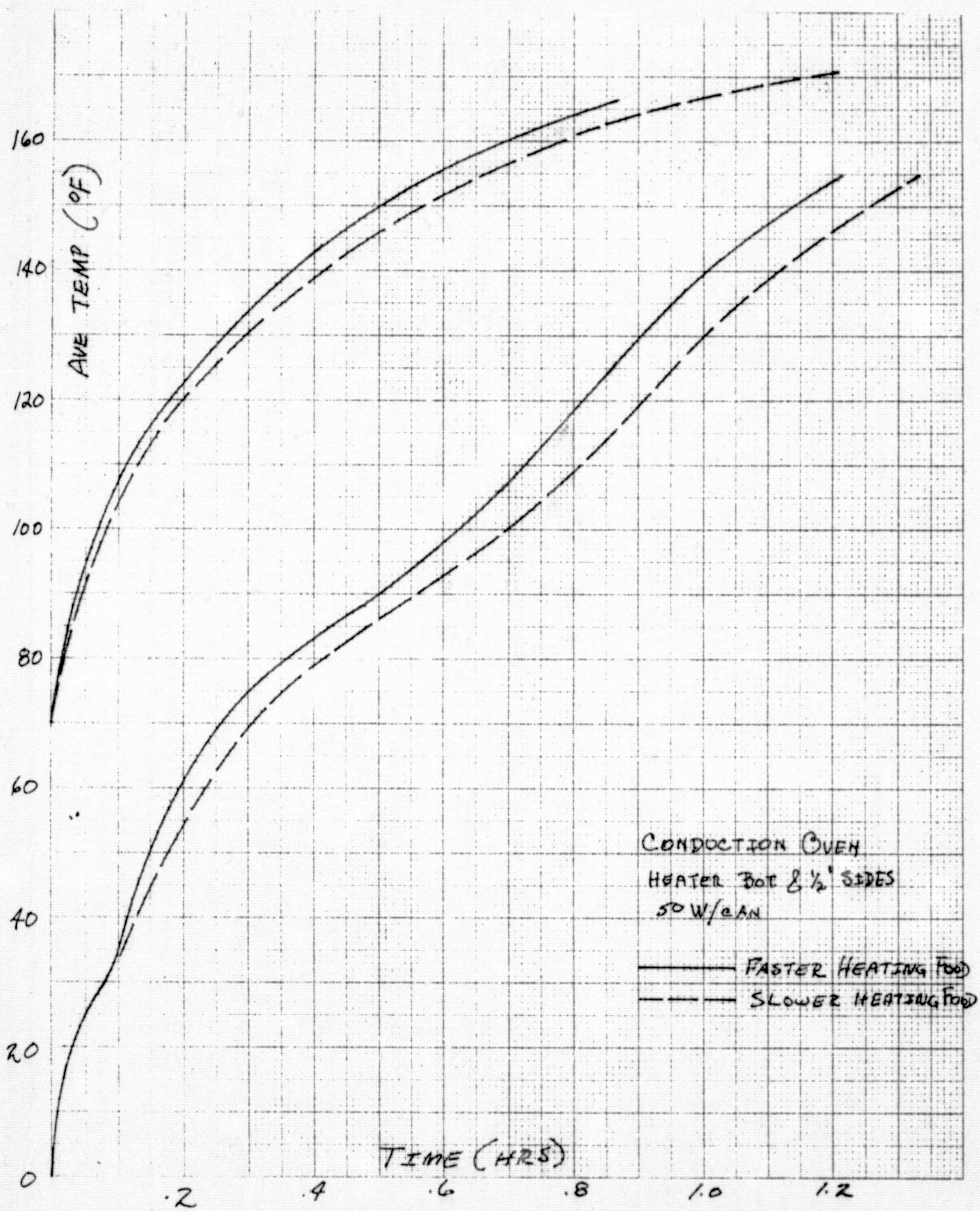


Figure 3-27. Conduction Oven Heating Curves for Range of Food Types.

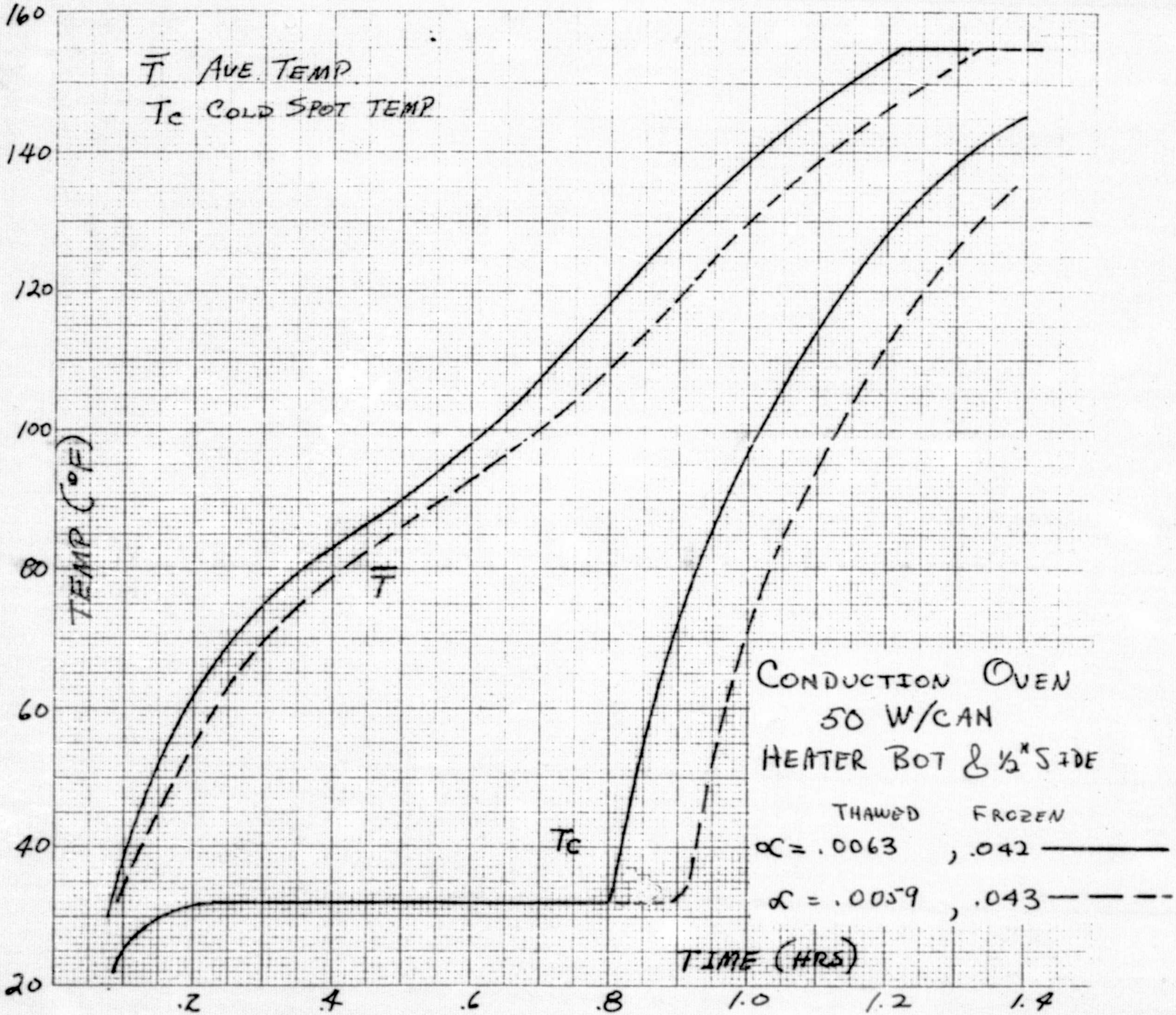


Figure 3-28. Heating Curves for Range of Frozen Food

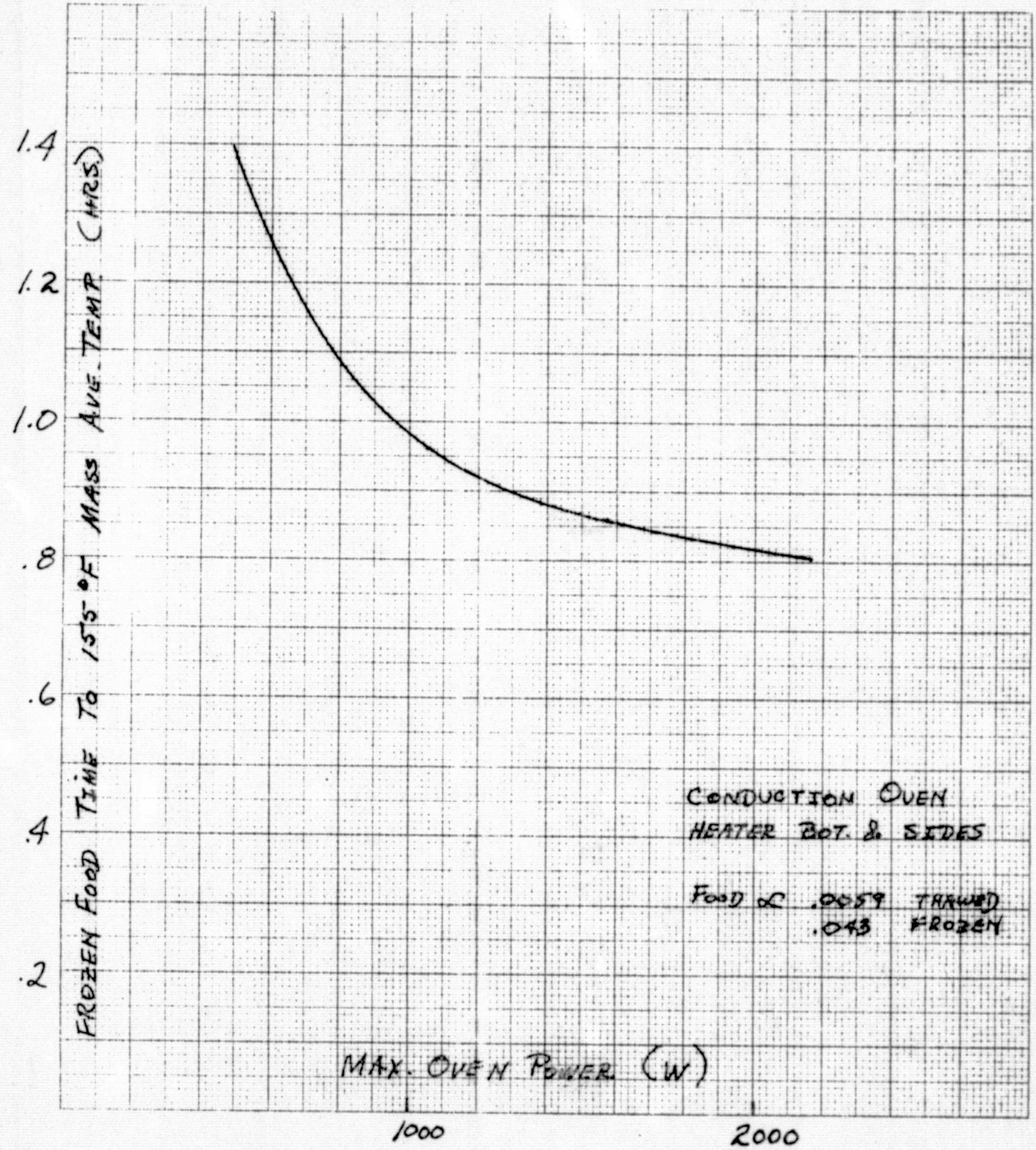


Figure 3-29. The Effect of Maximum Oven Power on the Time to Heat Frozen Food from 0° to 155°F

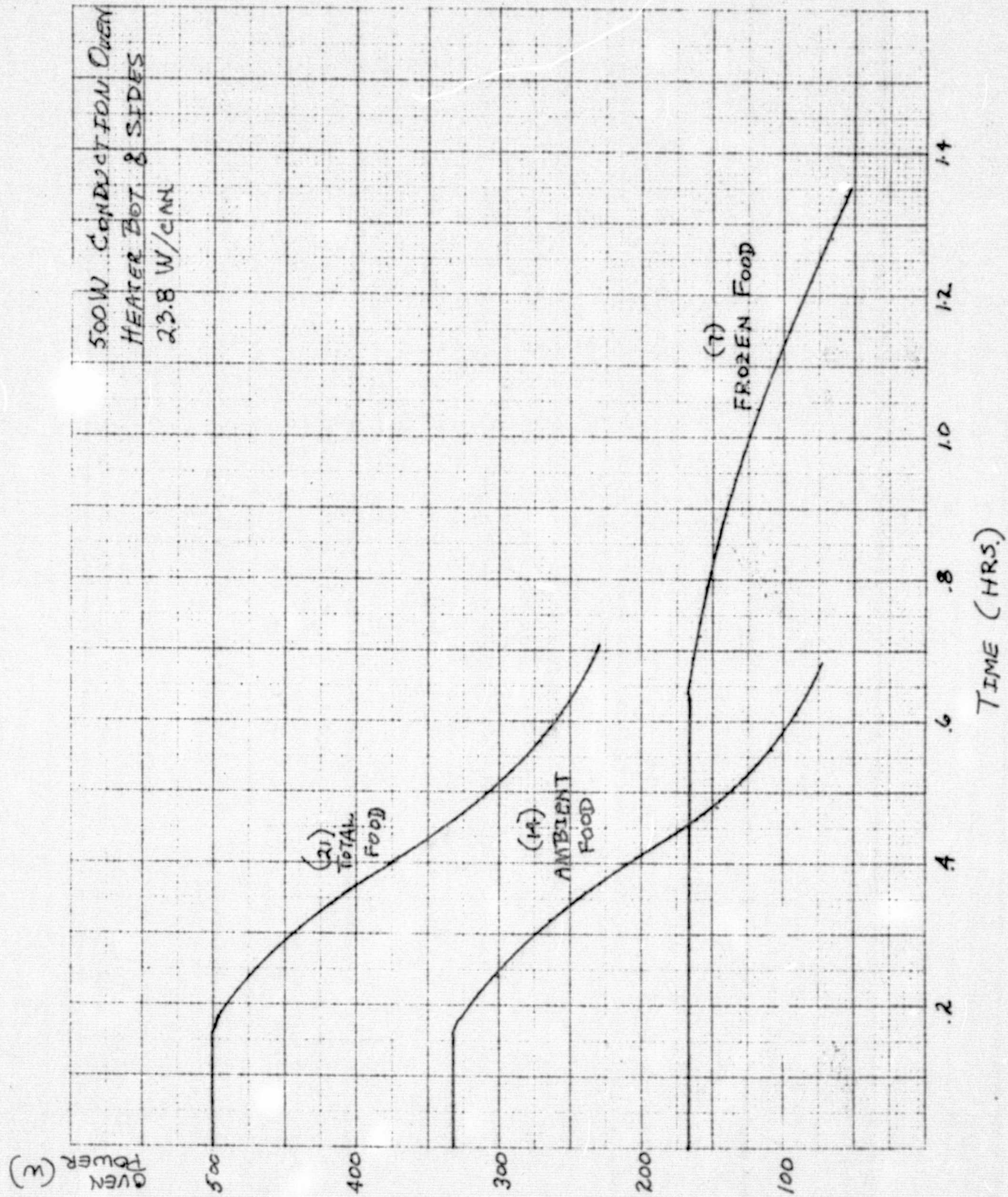


Figure 3-30. Time Average Oven Power Usage with Time for a 500 Watt Maximum Oven Power

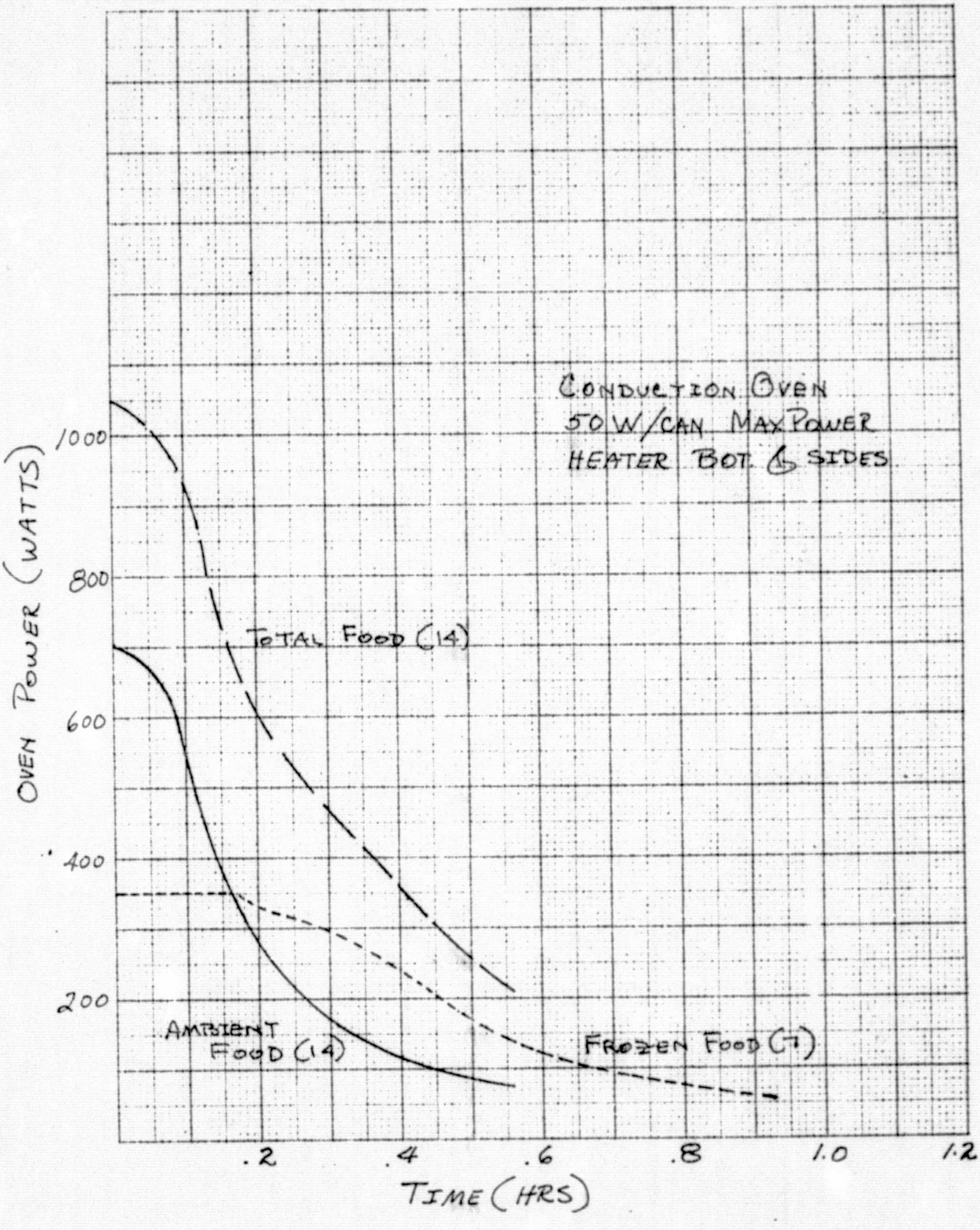


Figure 3-31. Time Average Oven Power Usage with Time for a 1050 Watt Maximum Oven Power

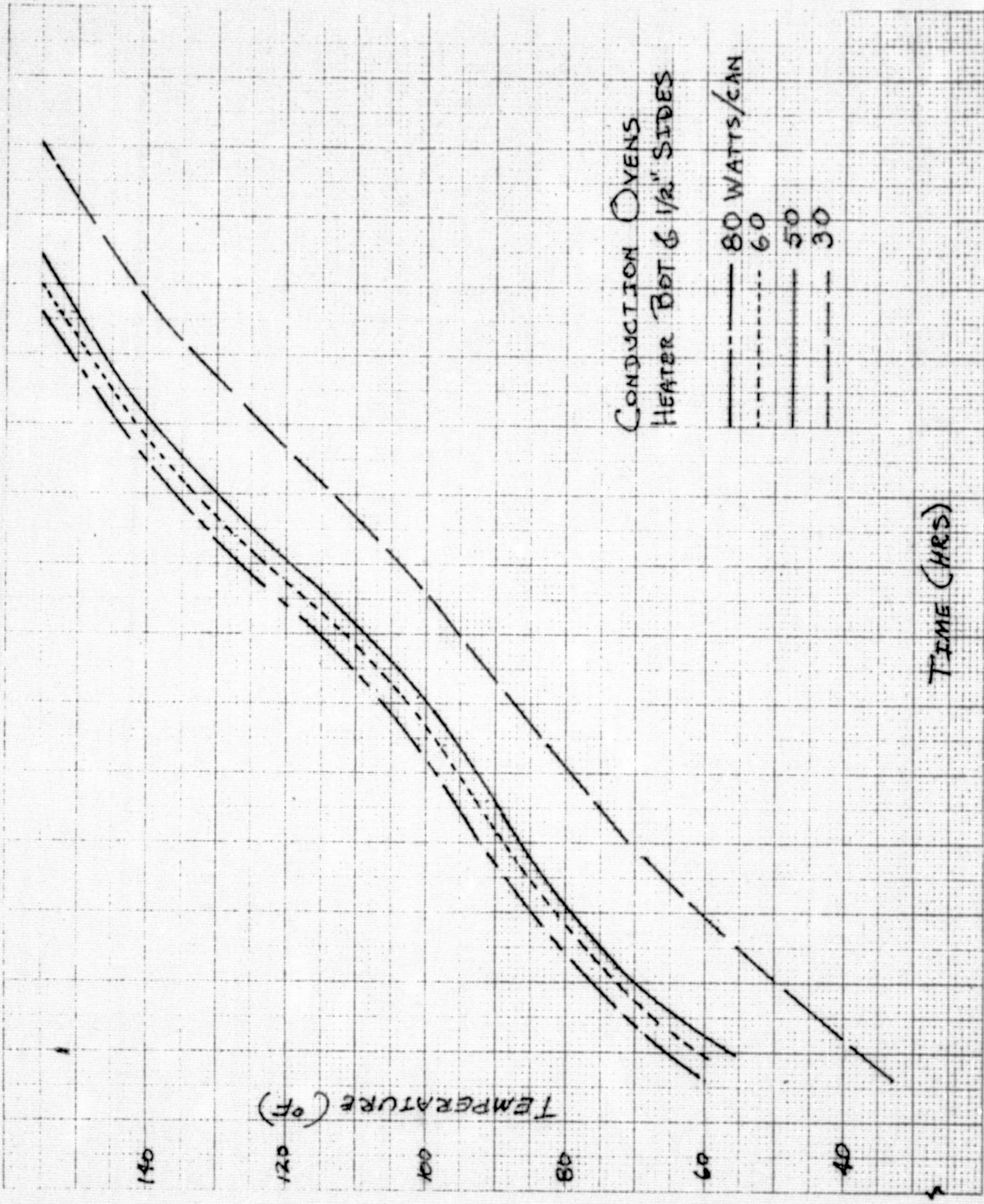


Figure 3-32. The Effect of Maximum Oven Power on the Heating Curve

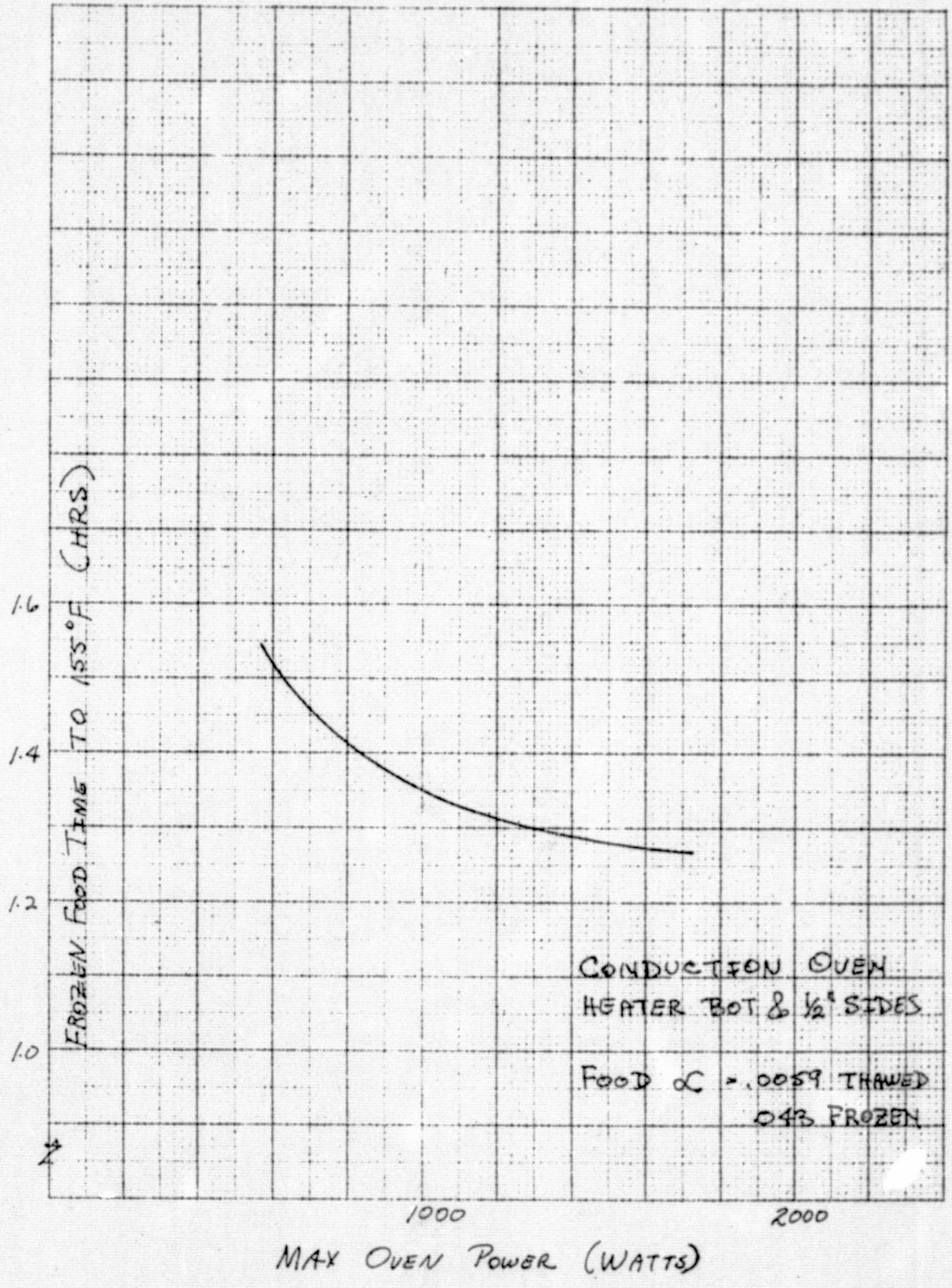


Figure 3-33. The Effect of Maximum Oven Power on the Time to Heat Frozen Food from 0° to 155°F

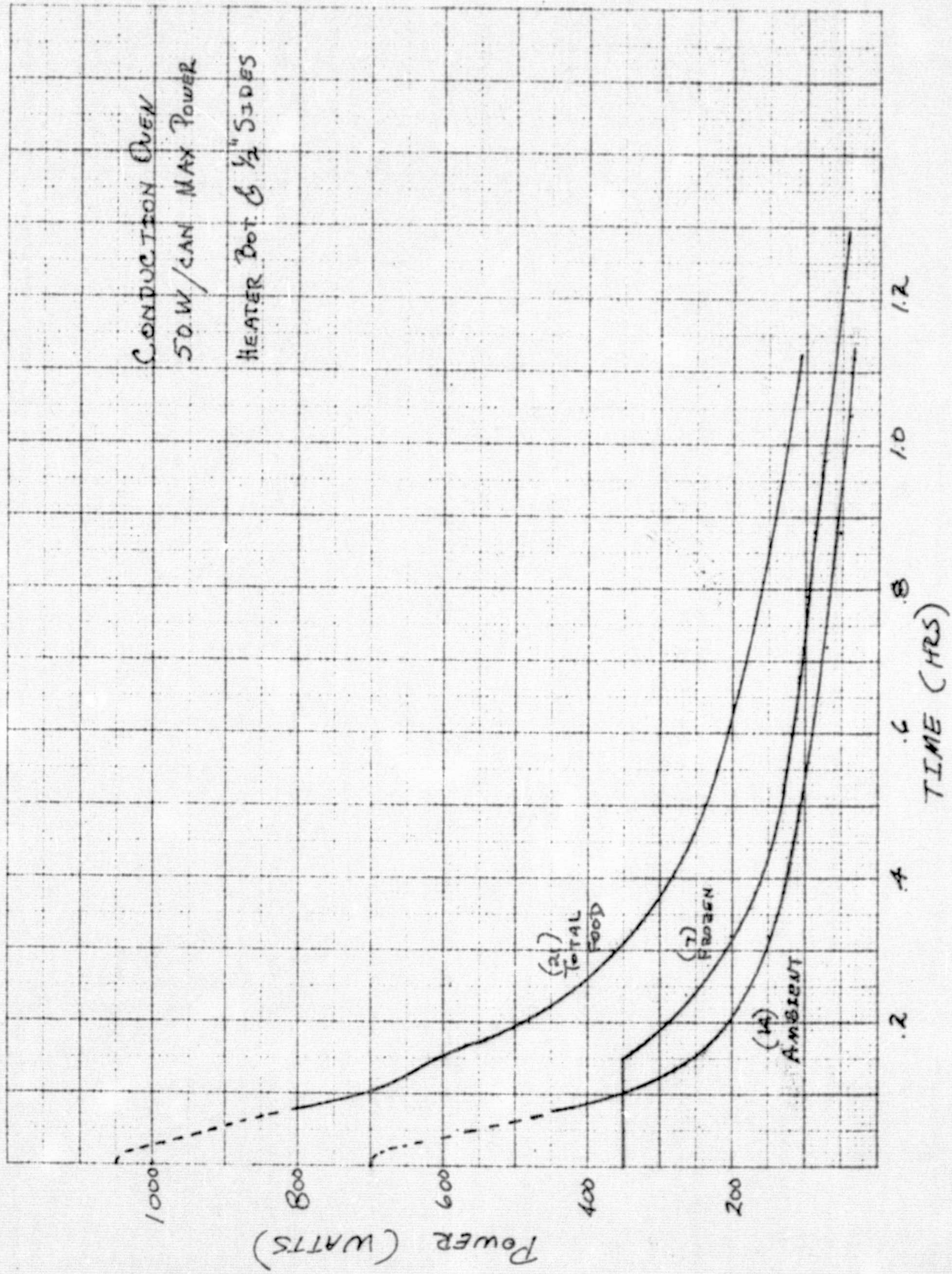


Figure 3-34. Time Average Oven Power Usage with Time

The curve in Figure 3-33 can be made to almost exactly coincide with the similar curve for the full side-heater oven (Figure 3-29), by shifting the abscissa 100 watts and the ordinate .24 hours. If one chose the same point on the break in the curve, and if this point were 1050 W for the full side heater, it would then be 950 W for the fixed, 1/2" side heater. If we add to this power, 50 watts for the wall heater used for the food holding function, the total oven power would be 1000 W.

3.2.4.3.3 Energy

The conduction oven energy consumption differs from the convection oven only in the heat leakage during active heating and in the holding power requirements. For the case of an oven loading of 7 frozen food and 14 thermostabilized food, the energy consumption at various times is:

	At Completion of Heating to 155°F	After 1 hr Holding	After 2 hr Holding
Energy Consumption (w-hr)	418	468	518

For a meal consisting of 21 thermostabilized foods the energy requirement including losses is

	At Completion of Heating to 150°F	After 1 hr Holding	After 2 hr Holding
Energy Consumption (w-hr)	236	286	336

3.2.4.4 Weight

The estimated weight of the conduction oven and its components is given in Table 3-2.

TABLE 3-2. CONDUCTION OVEN WEIGHT

Outer Structural Shell	7.31 pounds
Inner Shell	2.26
Insulation	1.09
Heater	0.66
Controls	3.32
Hardware	0.33
	14.97
Inserts (7)	10.56
Total Weight	25.53 pounds

3.2.4.5 Volume

The conduction oven volume is 1649 cubic inches. Its front face is 6.7 inches wide and 17.31 inches high for a front face area of 116 square inches.

3.3 Structural Design

The oven subassembly is considered a line replaceable unit of the galley subsystem, per paragraph 3.1.2.2.1 d and e of the Galley End Item Specification, FRC document MS148N0008, and as such is subject to bench handling shock environments. An additional consideration relating to handling loads is the human factors requirement and the handling loads induced per MIL-STD-1472. Other conditions which the oven must be capable of withstanding are the induced flight environments during launch (± 5 g in all directions) and the crash safety shock of paragraph 3.1.2.5.2.1 (Ref. MIL-STD-810, Method 516.1, Procedure III).

In order to design the supporting structure of the oven the dynamic response of the structure must be assumed. A conservative estimate because of structural damping, is a dynamic magnification factor of ten based on a rough estimate of 20 pounds oven weight, the ultimate load at the C.G. of the oven is 1000 pounds (Wt. x g's x Mag). Using this load the supporting structure can be designed to resist loads in all three directions. A fatigue check would also be required using the spectra from the Galley System End Item Specification. On completion of the design the response of the structure would be determined by test in order to verify the design assumptions and structural integrity.

The sides and door of the oven are designed to withstand a handling load of approximately 100 pounds ultimate. This is approximately the magnitude of force that could be applied by the arm of a person. (Ref. MIL-STD-1472 "Human Engineering Design Criteria for Military Systems, Equipment and Facilities, P. 80). In order to withstand this handling load the outer shell of the oven

would have to be stiffened either by integral ribs or stiffeners. The design will consider integral ribs and an analysis is given in Appendix C. The oven sides are considered as flat plates simply supported on all edges and a 100 pound load applied at the center of the panel. A criteria for the maximum deflection equal to half the panel thickness is established to prevent the panel edge members from acting as membrane restraining members.

The inner shell is not primarily structural and is to be supported off the outer shell with flexible supports in order to minimize thermal stresses. Internal equipment such as blowers, which represent masses subject to the induced accelerations during launch are connected to the ribs of the outer shell which serves as the inter-connection to the supporting structure of the galley.

As shown in detail in Appendix C, in order to adequately support a 100 pound handling load, the front and back panel should be reinforced by local webs 0.040 inches thick and 0.43 inches high. The panel thickness should be 0.040 inches.

The oven is supported by four shear pins. The mounting points are conservatively analyzed for a fatigue criterium based on repeated 5g launch loads and result in mounting bosses 0.20 inches thick, 0.82 inches diameter, a supporting 0.25 inch diameter titanium attachment bolt.

4.0 PREPARATION TIMELINES

The various food mix combinations require different preparation characteristics with respect to handling, rehydration and serving tray food assembly. Oven heating times also vary as a function of the oven type and oven contents. A ground rule of this study was that all thermostabilized and frozen food items were packaged in round aluminum cans similar to Skylab. Although no galley stowage previsions have been considered for these food items, it has been assumed that they will be either within the galley or immediately adjacent to the galley thereby readily accessible at meal preparation without time penalties for securing from a remote location.

The following series of timelines were prepared for the specified lunch and dinner mix of 2 thermostabilized plus 1 frozen food item, and 4 possible combinations of thermostabilized and rehydratable food items that could occur at breakfast.

The time lines for all meal types are summarized in Figure 4-1. The total preparation time for a meal depends on the required heating time. Table 4-1 gives the maximum heating times required for a meal containing frozen food, and for a meal containing only thermostabilized food. When the heating times are combined with the preparation times in Figure 4-1, the total preparation time including work time and open time can be calculated as shown in Table 4-2.

PREPARATION TIMELINES

A. 2 Thermostabilized, 1 Frozen (Lunch and/or Dinner)

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
4	4	1. Open insert stowage door
11	7	2. Remove insert
18	7	3. Place insert in work area
102	84	4. Repeat 2 and 3, 6 times
106	4	5. Close insert stowage door
110	4	6. Open canned food stowage door
118	8	7. Remove appropriate meal package
126	8	8. Open meal overwrap
131	5	9. Secure meal package to galley
135	4	10. Remove one can
139	4	11. Place can in appropriate can conduction sleeve
299	160	12. Repeat 10 and 11, 20 times
304	5	13. Remove empty meal overwrap from secured position
308	4	14. Open canned food stowage door
314	6	15. Place empty overwrap in can storage area
318	4	16. Close canned food stowage door
322	4	17. Open oven door
328	6	17a. Remove insert from work area
336	8	18. Place insert in oven
420	84	19. Repeat 18, 6 times
423	3	20. Switch oven "On"
427	4	21. Close oven door
432	5	22. Set timer

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)		Function
4	4	23.	Remove 1 personal wipe from wipe compartment
7	3	24.	Place 1 personal wipe on tray
49	42	25.	Repeat 23 and 24, 6 times
53	4	26.	Open wastat compartment
56	3	27.	Remove 7 wastat packages
60	4	28.	Close wastat compartment
62	2	29.	Separate 1 wastat package
65	3	30.	Place 1 wastat package in tray
95	30	31.	Repeat 29 and 30, 6 times
99	4	32.	Open condiment tray
102	3	33.	Remove required condiments for one tray
107	5	34.	Place required condiments in one tray
155	48	35.	Repeat 33 and 34, 6 times
159	4	36.	Close condiment tray
163	4	37.	Open "Bev/Rte" door
171	8	38.	Remove appropriate "Bev/Rte" meal package
179	8	39.	Open "Bev/Rte" meal overwrap
184	5	40.	Secure "Bev/Rte" overwrap to galley
188	4	41.	Remove 1 Rte
192	4	42.	Place 1 Rte in appropriate tray
240	48	43.	Repeat 41 and 42, 6 times
244	4	44.	Remove 1 "Bev" from overwrap
249	5	45.	Read water quantity requirement on Bev Pac
253	4	46.	Set water dispenser for quantity requirement
256	3	47.	Insert Bev Pac in retention device
258	2	48.	Insert dispense probe into Bev Pac
284	26.25 sec (avg)	49.	Water dispense time (30 sec for 8 oz) (22.5 sec for 6 oz)
286	2	50.	Remove probe from Bev Pac
289	3	51.	Remove Bev Pac from retention device
294	5	52.	Place Bev Pac in tray
999	705	53.	Repeat 44 thru 52, 13 times

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
4	4	54. Open oven door
12	8	55. Remove 1 insert from oven (Step 18)
20	8	56. Place insert in appropriate tray
116	96	57. Repeat 55 and 56, 6 times
120	4	58. Open canned food stowage door
124	4	59. Remove empty meal overwrap (Step 15)
128	4	60. Close canned food stowage door
133	5	61. Secure overwrap to galley (Step 9)
141	8	62. Remove lid from can
148	7	63. Place lid in empty overwrap
448	300	64. Repeat 62 and 63, 20 times
453	5	65. Remove overwrap from secured position
460	7	66. Seal overwrap
466	6	67. Place overwrap in trash stowage area
		68. Serve meals

C. 2 Thermostabilized, 1 Rehydratable.

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
4	4	1. Open insert stowage door
11	7	2. Remove insert
18	7	3. Place insert in work area
102	84	4. Repeat 2 and 3, 6 times
106	4	5. Close insert stowage door
110	4	6. Open canned food stowage door
118	8	7. Remove appropriate meal package
126	8	8. Open meal overwrap
131	5	9. Secure meal package to galley
135	4	10. Remove one can
139	4	11. Place can in appropriate can conduction sleeve
243	104	12. Repeat 10 and 11, 13 times
248	5	13. Remove empty meal overwrap from secured position
252	4	14. Open canned food stowage door
258	6	15. Place empty overwrap in can storage area
262	4	16. Close canned food stowage door
266	4	17. Open oven door
272	6	17a. Remove insert from work area
280	8	18. Place insert in oven
364	84	19. Repeat 18, 6 times
367	3	20. Switch oven "On"
371	4	21. Close oven door
376	5	22. Set timer
4	4	23. Remove 1 personal wipe from wipe compartment
7	3	24. Place 1 personal wipe on tray
49	42	25. Repeat 23 and 24, 6 times
53	4	26. Open wastat compartment
56	3	27. Remove 7 wastat packages
60	4	28. Close wastat compartment

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)		Function
62	2	29.	Separate 1 wastat package
65	3	30.	Place 1 wastat package in tray
95	30	31.	Repeat 29 and 30, 6 times
99	4	32.	Open condiment tray
102	3	33.	Remove required condiments for one tray
107	5	34.	Place required condiments in one tray
155	48	35.	Repeat 33 and 34, 6 times
159	4	36.	Close condiment tray
165	4	37.	Open "Rehydratable" door
173	8	38.	Remove appropriate "Rehydratable" meal package
181	8	39.	Open "Rehydratable" meal overwrap
186	5	40.	Secure "Rehydratable" overwrap to galley
190	4	41.	Remove 1 rehydratable from overwrap
195	5	42.	Read water quantity requirement on rehydratable package
199	4	43.	Set water dispenser for quantity required
202	3	44.	Insert rehydratable pac in retention device
204	2	45.	Insert dispense probe into rehydratable pac
372	16.8	46.	Water dispense time (16.8 sec for 4.46 oz)
374	2	47.	Remove probe from rehydratable pac
377	3	48.	Remove rehydratable pac from retention device
381	4	49.	Store rehydratable pac in "Intermediate Storage Receptacle"
644	263	50.	Repeat 41 through 49, 6 times
648	4	51.	Open oven door
652	8	52.	Remove one insert (or slide out of oven sufficiently to gain access to rehydratable cavity
656	4	53.	Remove one rehydratable from "Intermediate Storage Receptacle"
660	4	54.	Place rehydratable in insert
668	8	55.	Replace insert in oven

Accumulated Elapsed Time (sec.)	Incremental Time (Sec.)	Function
812	144	56. Repeat 52 through 55, 6 times
816	4	57. Close oven door
820	4	58. Open "Bev/Rte" door
828	8	59. Remove appropriate "Bev/Rte" meal package
836	8	60. Open "Bev/Rte" meal overwrap
841	5	61. Secure "Bev/Rte" overwrap to galley
845	4	62. Remove 1 Rte
849	4	63. Place 1 Rte in appropriate tray
897	48	64. Repeat 62 and 63, 6 times
901	4	65. Remove 1 "Bev" from overwrap
906	5	66. Read water quantity requirement on Bev Pac
910	4	67. Set water dispenser for quantity required
913	3	68. Insert Bev Pac in retention device
915	2	69. Insert dispense probe into Bev Pac
941	26.25 sec (avg)	70. Water dispense time (30 sec for 8 oz) (22.5 sec for 6 oz)
943	2	71. Remove probe from Bev Pac
946	3	72. Remove Bev Pac from retention device
951	5	73. Place Bev Pac in tray
1656	705	74. Repeat 65 thru 73, 13 times
4	4	75. Open oven door
12	8	76. Remove 1 insert from oven
20	8	77. Place insert in appropriate tray
116	96	78. Repeat 76 and 77, 6 times
120	4	79. Open canned food stowage door
124	4	80. Remove empty meal overwrap
128	4	81. Close canned food stowage door
133	5	82. Secure overwrap to galley
141	8	83. Remove lid from can
148	7	84. Place lid in empty overwrap
343	195	85. Repeat 83 and 84, 13 times
348	5	86. Remove overwrap from secured position
355	7	87. Seal overwrap
361	6	88. Place overwrap in trash stowage area
		89. Serve meals

D. 1 Thermostabilized, 2 Rehydratable.

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
4	4	1. Open insert stowage door
11	7	2. Remove insert
18	7	3. Place insert in work area
102	84	4. Repeat 2 and 3, 6 times
106	4	5. Close insert stowage door
110	4	6. Open canned food stowage door
118	8	7. Remove appropriate meal package
126	8	8. Open meal overwrap
131	5	9. Secure meal package to galley
135	4	10. Remove one can
139	4	11. Place can in appropriate can conduction sleeve
187	48	12. Repeat 10 and 11, 6 times
192	5	13. Remove empty meal overwrap from secured position
196	4	14. Open canned food stowage door
202	6	15. Place empty overwrap in can storage area
206	4	16. Close canned food stowage door
210	4	17. Open oven door
216	6	17a. Remove insert from work area
224	8	18. Place insert in oven
308	84	19. Repeat ;17a and 18, 6 times
311	3	20. Switch oven "On"
315	4	21. Close oven door
320	5	22. Set timer
4	4	23. Remove 1 personal wipe from wipe compartment
7	3	24. Place 1 personal wipe on tray
49	42	25. Repeat 23 and 24, 6 times
53	4	26. Open wastat compartment
56	3	27. Remove 7 wastat packages

Accumulated Elapsed Time (Sec)	Incremental Time (Sec.)	Function
60	4	28. Close wastat compartment
62	2	29. Separate 1 wastat package
65	3	30. Plase 1 wastat package in tray
95	30	31. Repeat 29 and 30, 6 times
99	4	32. Open condiment tray
102	3	33. Remove required condiments for one tray
107	5	34. Place required condiments in one tray
155	48	35. Repeat 33 and 34, 6 times
159	4	36. Close condiment tray
163	4	37. Open "Rehydratable" door
171	8	38. Remove appropriate "Rehydratable" meal package
179	8	39. Open "Rehydratable" meal overwrap
184	5	40. Secure "Rehydratable" overwrap to galley
188	4	41. Remove 1 rehydratable from overwrap
193	5	42. Read water quantity requirement on "Rehyd" package
197	4	43. Set water dispenser for quantity required
200	3	44. Insert rehydratable pac in retention device
202	2	45. Insert dispense probe into rehydratable pac
219	16.8	46. Water dispense time (16.8 sec for 4.46 oz)
221	2	47. Remove probe from rehydratable pac
224	3	48. Remove rehydratable pac from retention device
228	4	49. Store rehydratable pac in "Intermediate storage receptacle"
797	569	50. Repeat 41 through 49, 13 times
4	4	51. Open oven door
12	8	52. Remove one insert (or slide out of oven sufficiently to gain access to rehydratable cavity)
16	4	53. Remove one rehydratable from "intermediate storage receptacle"
20	4	54. Place rehydratable in insert

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)		Function
28	8	55.	Replace insert in oven
172	144	56.	Repeat 52 through 55, 6 times
176	4	57.	Close oven door
180	4	58.	Open "Bev/Rte" door
188	8	59.	Remove appropriate "Bev/Rte" meal package
196	8	60.	Open "Bev/Rte" meal overwrap
201	5	61.	Secure "Bev/Rte" overwrap to galley
205	4	62.	Remove 1 Rte
209	4	63.	Place 1 Rte in appropriate tray
257	48	64.	Repeat 62 and 63, 6 times
261	4	65.	Remove 1 "Bev" from overwrap
266	5	66.	Read water quantity requirement on Bev Pac
270	4	67.	Set water dispenser for quantity required
270	3	68.	Insert Bev Pac in retention device
272	2	69.	Insert dispense probe into Bev Pac
298	26.25 sec	70.	Water dispense time (30 sec for 8 oz.) (22.5 sec for 6 oz.)
300	2	71.	Remove probe from Bev Pac
303	3	72.	Remove Bev Pac for retention device
308	5	73.	Place Bev Pac in tray
1013	705	74.	Repeat 65 thru 73, 13 times
4	4	75.	Open oven door
12	8	76.	Remove 1 insert from oven
20	8	77.	Place insert in appropriate tray
116	96	78.	Repeat 76 and 77, 6 times
120	4	78a.	Close oven door
124	4	79.	Open canned food stowage door
128	4	80.	Remove empty meal overwrap
132	4	81.	Close canned food stowage door
137	5	82.	Secure overwrap to galley

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
145	8	83. Remove lid from can
152	7	84. Place lid in empty overwrap
242	90	85. Repeat 83 and 84, 6 times
247	5	86. Remove overwrap from secured position
254	7	87. Seal overwrap
260	6	88. Place overwrap in trash stowage area
		89. Serve meals

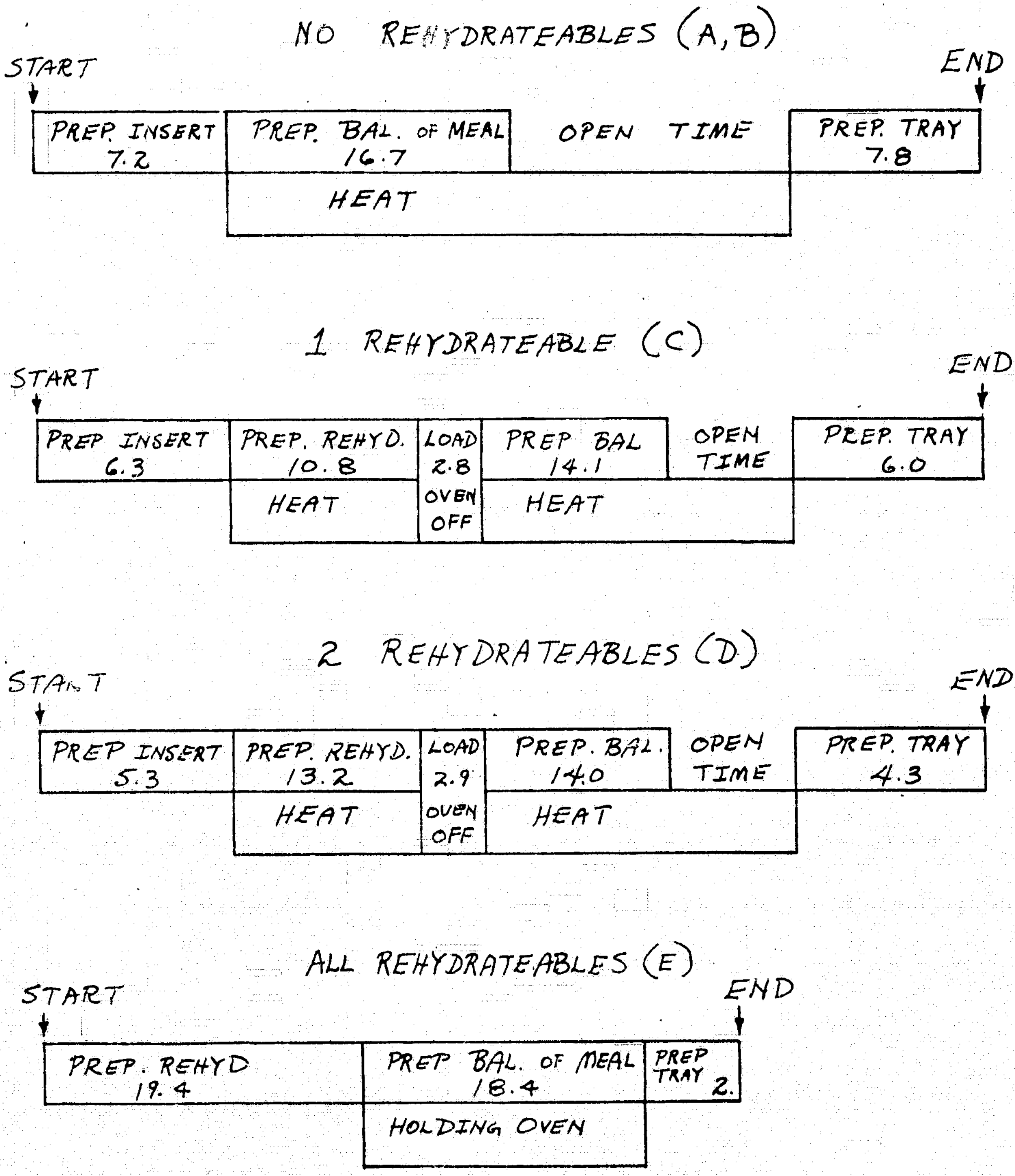
E. 3 Rehydratables.

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
4	4	1. Open insert stowage door
11	7	2. Remove insert
18	7	3. Place insert in work area
102	84	4. Repeat 2 and 3, 6 times
106	4	5. Close insert stowage door
110	4	6. Open "Rehydratable" door
118	8	7. Remove appropriate "Rehydratable" meal package
126	8	8. Open "Rehydratable" meal overwrap
131	5	9. Secure "Rehydratable" overwrap to galley
135	4	10. Remove 1 rehydratable from overwrap
140	5	11. Read water quantity requirement on rehyd package
144	4	12. Set water dispenser for quantity required
147	3	13. Insert rehydrable pac in retention device
149	2	14. Insert dispense probe into rehydratable pac
166	16.8	15. Water dispense time (16.8 sec for 4.46 oz)
168	2	16. Remove probe from rehydratable pac
171	3	17. Remove rehydratable pac from retention device
175	4	18. Place rehydratable in insert
1051	876(14'36")	19. Repeat 10 thru 18, 20 times (20 x 43.8)
1055	4	20. Open oven door
1061	6	21. Remove one insert from work area
1069	8	22. Place one insert in oven
1153	84	23. Repeat 21 and 22, 6 times
1157	4	24. Close oven door
1162	5	25. Set control (to "Hold")
4	4	26. Open tray storage compartment
11	7	27. Remove one tray
18	7	28. Place one tray in work area
102	84	29. Repeat 27 and 28, 6 times

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)		Function
106	4	30.	Close tray storage compartment
110	4	31.	Remove 1 personal wipe from wipe compartment
113	3	32.	Place 1 personal wipe on tray
155	42	33.	Repeat 23 and 24, 6 times
159	4	34.	Open wastat compartment
162	3	35.	Remove 7 wastat packages
166	4	36.	Close wastat compartment
168	2	37.	Separate 1 wastat package
171	3	38.	Place 1 wastat package in tray
201	30	39.	Repeat 29 and 30, 6 times
205	4	40.	Open condiment tray
208	3	41.	Remove required condiments for one tray
213	5	42.	Place required condiments in one tray
261	48	43.	Repeat 33 and 34, 6 times
265	4	44.	Close condiment tray
269	4	45.	Open Bev/Rte door
277	8	46.	Remove appropriate "Bev/Rte" meal package
285	8	47.	Open "Bev/Rte" Meal Overwrap
290	5	48.	Secure 'Bev/Rte" overwrap to galley
294	4	49.	Remove 1 Rte
298	4	50.	Place 1 Rte in appropriate tray
346	48	51.	Repeat 62 and 63, 6 times
350	4	52.	Remove 1 "Bev" from overwrap
355	5	53.	Read water quantity requirement on Bev Pac
359	4	54.	Set water dispenser for quantity required
362	3	55.	Insert Bev Pac in retention device
364	2	56.	Insert dispense probe into Bev Pac
390	26.25 sec (avg.)	57.	Water dispense time (30 sec for 8 oz) (22.5 sec for 6 oz)
392	2	58.	Remove probe from Bev Pac
395	3	59.	Remove Bev Pac from retention device

Accumulated Elapsed Time (Sec.)	Incremental Time (Sec.)	Function
400	5	60. Place Bev Pac in tray
1105	705	61. Repeat 65 thru 73, 13 times
4	4	62. Open oven door
12	8	63. Remove 1 insert from oven
20	8	64. Place insert in appropriate tray
116	96	65. Repeat 63 and 64, 6 times
120	4	66. Close oven door
		67. Serve meals

FIG. 4-1 MEAL PREPARATION TIMES SUMMARY



ALL TIMES IN MINUTES

TABLE 4-1 TIME TO HEAT (MIN.)

	FROZEN FOOD 0-155 °F	THERMOSTAB. FOOD 70-155 °F
CONVECTION 500W, h=4	77	46
CONDUCTION 1050 W	80	40

FOOD MIX	TOTAL TIME		OPEN TIME		WORK TIME
	CONV.	COND.	CONV.	COND.	
A. 2 FROZEN 1 THERMO.	92	95	60	63	32
B. ALL THERMO.	61	55	29	23	32
C. 2 THERMO. 1 REHYD.	61	55	21	15	40
D. 1 THERMO. 2 REHYD.	59	53	19	13	40
E. ALL REHYD (BASELINE)	40		0		40

TABLE 4-2 TOTAL PREPARATION TIME

5.0 WATER REQUIREMENTS

The addition of thermostabilized and frozen food items to replace rehydratable food items will obviously result in a reduction of daily water needed for rehydration. The ground rules for the study established that a mix of 2 thermostabilized plus 1 frozen item, all requiring heating, would replace 3 hot rehydratables at lunch and dinner. No more than 2 frozen items per man day were to be carried. At breakfast, any combination of thermostabilized and/or rehydratable food items would be possible. The food mix to be considered is shown in Table 5-1, and indicates the four combinations possible for breakfast as well as the fixed relationship of thermostabilized and frozen at lunch and dinner. The oven sizing requirements can be summarized from Table 5-1 by multiplying any of the combinations shown times 7 crewmen (i.e., breakfast combination (b) would consist of 14 thermostabilized + 7 rehydratable items to be heated in the oven).

Table 5-1

Meal	Food Type Mix		
	Thermostabilized	Frozen	Rehydratable
Breakfast			
a)	3		
b)	2		1
c)	1		2
d)			3
Lunch	2	1	
Dinner	2	1	

Oven Study Food Mix Per Man Day

The water quantities required per food or beverage package have been previously established during the original food system study as follows:

Hot Beverage	6 oz.
Cold Beverage	8 oz.
Rehydratable (Hot or cold)	5.46 oz. maximum 4.46 oz. normal
Thermostabilized	0
Frozen	0

5.1 Food Item Analysis

Based on Table 5-1, each food type requirement can be compared to the baseline system of all-rehydratables to establish the change in food types for the various combinations shown. Table 5-2 depicts the options of meal plans considered in the oven study (4 breakfast combinations and a fixed relationship at lunch and dinner) as compared to the all rehydratable baseline. All the thermostabilized and frozen food items require heating in the oven and for purposes of determining the most critical oven requirements, all rehydratables at breakfast are also assumed to be hot. This results in a greater hot water requirement than for the baseline mix, where the requirement was based on a mix of hot and cold rehydratables. For snacks and overage, it is assumed that baseline rehydratables would be used thereby not impacting water quantity, heater power or energy requirements.

Table 5-2

Meal	Oven Study	Baseline	Water Requirement Food
Breakfast	a) 21 Thermostabilized		a) - 9 hot rehydratables and - 5 cold rehydratables
	b) 14 Thermostabilized + 7 Rehydratables		b) - 2 hot rehydratables and - 5 cold rehydratables
	c) 7 Thermostabilized + 14 Rehydratables	9 hot rehydratables + 5 cold rehydratables	c) + 5 hot rehydratables and - 5 cold rehydratables
	d) 21 Rehydratables		d) + 12 hot rehydratables and - 5 cold rehydratables
Lunch	14 Thermostabilized + 7 Frozen	10 hot rehydratables + 4 cold rehydratables	- 10 hot rehydratables and - 4 cold rehydratables
Dinner	14 Thermostabilized + 7 Frozen	20 hot rehydratables + 1 cold rehydratable	- 20 hot rehydratables and 1 cold rehydratable

FOOD ITEM ANALYSIS PER CREW DAY

Table 5-2 now defines the change in the number of rehydratables required for each meal when the new oven study requirements are imposed. For each of these conditions, the associated water quantities can now be calculated.

5.2 WATER DEMAND ANALYSIS

The rehydratable food items identified in Table 5-2 are converted to nominal water requirements in Table 5-3, based on 4.46 ounces of water required for either a hot or cold rehydratable. The baseline demands can be totalled for hot (22.71#) and cold (18.07#) water, which confirms the daily nominal demand specified in the Galley Water System ICD number MS148N0005 Rev. A, paragraph 3.3.1.3. The change in water requirements shown in Table 5-3 can be calculated as follows:

Maximum daily hot water decrease = Sum of lunch + dinner + breakfast (a) = 10.88#

Minimum daily hot water decrease = Sum of lunch + dinner + breakfast (c) = 5.03#

Daily cold water decrease = Sum of breakfast + lunch + dinner = 2.79#

Although the daily demand for water decreases as shown above, it must also be noted that breakfast combinations (c) and (d) actually require an increase in capacity. This means that the hot water system must be expanded in size. However, as previously shown, the daily demand is decreased due to the elimination of all rehydratables at lunch and dinner. The implication therefore is that after expending the hot rehydration water at breakfast, there is only the beverage demand for the rest of the day. Consequently, the recovery time to reheat can be increased resulting in a lower power draw on the system.

TABLE 5-3

Meal	Oven Study Hot	Oven Study Cold	Baseline Hot	Baseline Cold	Water Requirement Hot	Water Requirement Cold
	a) 0	0			a) -2.51#	-1.39#
Breakfast	b) 1.95#	0	2.51#	1.39#	b) - .56#	-1.39#
	c) 3.90#	0			c) +1.39#	-1.39#
	d) 5.85#	0			d) +3.34#	-1.39#
Beverage	2.63#	3.5#	2.63#	3.5#	0	0
Lunch	0	0	2.79#	1.12#	-2.79#	-1.12#
Beverage	2.63#	3.5#	2.63#	3.5#	0	0
Dinner	0	0	5.58#	0.28#	-5.58#	-0.28#
Beverage	2.63#	3.5#	2.63#	3.5#	0	0
Snacks + Overage	3.94#	4.78#	3.94#	4.78#	0	0
			22.71#	18.07#		

COMPARATIVE NOMINAL WATER REQUIREMENTS

In order to determine the maximum meal demand impact, a comparison can be made to the baseline requirement of 15.45# as defined in ICD document MS148N0005 Rev. A, paragraph 3.3.1.2. Using breakfast option (b) of 21 rehydratables at 5.46 ounces each (maximum) = 7.17# of water. The maximum beverage quantity determined from the previous food study was 23 hot beverages per meal at 6 ounces each = 8.62# of water. The sum 15.79#, minus 15.45# produces an increase of 0.34# of water for the maximum meal.

The baseline cold water maximum meal demand is 16.78# of water. A maximum of 24 cold beverages was determined from the previous food study at 8 ounces each = 12# of water. The cold water demand will therefore decrease 4.78# at the maximum meal.

6.0 CONVECTION Vs CONDUCTION OVEN

6.1 Oven Comparison Matrix

OVEN COMPARISON

	Baseline	Convection	Conduction
Weight (Pounds)	18.58	26.02	25.53
Volume (In^3)	1383	1735	1649
Face Area (In^2)	98	126	116
Power (Watts)	50	500	1100
Preparation Time (Min.)			
All Rehyd.	40	40	40
No Frozen	-	59-61	53-55
Some Frozen	-	92	95

6.2 Qualitative Comparison

The convection and conduction ovens are distinguished by the following non-quantitative factors.

a. Adaptability to future changes in package shape. The conduction oven, since intimate contact is required between food package and heated surface, cannot tolerate a change in shape of the food package. The convection oven is more tolerant. The heat transfer coeffficient may change somewhat with package shape but the convection oven could successfully accommodate shape changes.

b. The conduction oven tray insert encloses the food cans more completely than the convection oven insert, so there is exposure of the hot cans to the crew during transfer from the oven to the tray. This may not be a strong factor since the temperature of the plastic inserts would require some insulated glove for handling in any event.

c. The convection oven heats more uniformly so that if the food can not be stirred it would require a lower average temperature than the conduction oven to produce a given cold spot minimum temperature.

d. Cost of the conduction oven would be higher than the convection oven due to the requirement of 21 individual temperature controllers.

e. The frequent making and breaking of power connections in the conduction oven tray insert may in time present a reliability problem.

f. Improvement in heating performance can be made more readily in the convection oven since a conservative heat transfer coefficient was used and a developed oven could exceed it. To improve the conduction oven performance, a larger portion of the surface area would have to be heated. This would prove difficult and would add additional weight and volume.

6.3 Crew Size

The oven is sized for a crew of seven. There is the possibility, however, that frequently the crew may number only four, or that shift eating may be scheduled. In this event, if the galley design were sufficiently flexible, it would be possible to save weight by using a lower capacity oven consisting of four tray inserts. The conduction oven subdivision is not as straightforward, but an oven capacity of four inserts could be designed employing two blowers. If this approach were worthwhile, two ovens would be installed when a load capacity of seven inserts were required.

6.4 Impact on Galley Design Baseline

Aside from the additional oven volume requirements given in Section 6.1, and the impact on water requirements discussed in Section 5.0, the food stowage liners and the waste collection volume will be impacted by the addition of canned food to the food mix.

6.4.1 Food Liners

Beverage and RTE food quantities are considered the same for both the baseline system and for the active heating system. Two factors tend to increase the volume of the food liner devoted, in the baseline system, to rehydratable food, and now to a mixture of rehydratable and canned food. First the round can packs less efficiently than the square rehydratable package. Secondly, the baseline system considered two meals with 14 rehydratables while this study considers each meal to be composed of 21 food packages. However, the 14 frozen cans per day are assumed to be stored outside the galley. The net effect, if we consider the one meal per day in which mixtures of thermostabilized and rehydratable food to be composed of roughly 50% each, is to increase the volume requirement by about 9%. This is not considered very significant because the assumptions of food mix may not be accurate. Probably the inefficiency in packing will be cancelled by the storage of frozen food cans outside the galley.

6.4.2 Trash Containers

The impact on trash containers is expected to be significant for two reasons. It is assumed that all food packages regardless of origin, are placed in the galley trash containers. In addition, for aluminum cans the ratio of trash stowage volume to initial stowage volume will be significantly greater than 1:1 as used for rehydratable packages. The aluminum cans are not easily compressible and do not nest. The actual volume fraction achieved will depend on the care taken in trash stowage and may be as high as 2:1. If the ratio is greater than 1:1 then recycling the food storage volume with trash volume will not suffice. Additional space in or outside of the galley must be used.

6.5 Impact on Shuttle Design Baseline

6.5.1 Power

Active heating will require 500-1000 watts more power than provided in the baseline galley. In addition, power must be supplied for the freezer requirement.

6.5.2 Energy

With a baseline food mix of 40 hot rehydratables per 7 man-day, and an active heating system food mix of 14 frozen cans, 40 thermostabilized cans and 11 hot rehydratables per 7 man-day, the difference in energy consumption for a 42 man-day mission is approximately 3.58 KWH.

6.5.3 Water

On average, the use of whole food will reduce the requirement for water by about 11 pounds per day for a crew of seven.

6.5.4 Volume

The galley itself aside from trash container requirement noted in 6.4.2 will probably not change significantly. However, the shuttle must provide additional stowage for the frozen food and its freezer.

6.5.5 Weight

The additional weight of food alone for the active heating system compared to the baseline is approximately 115 pounds for a 42 man-day mission.

7.0 SUMMARY

7.1 Weight, Volume and Power Penalties

The increases to the baseline system for each of the active heating systems is summarized below.

Item Increases	Convection	Conduction
Weight (Lbs.)	7.44	6.95
Volume ($In.^3$)	352	266
Face Area ($In.^2$)	28	18
Power (Watts)	450	1050
Preparation Time (Min.)		
No Frozen	19-21	13-15
Some Frozen	52	55

8.0 RECOMMENDATIONS

8.1 Selection of Active Oven Type

The two active oven types do not differ substantially in heating performance or weight. The conduction oven has some advantage in volume but this is not considered a very important property. The convection oven is recommended over the conduction oven for the following reasons.

a. The power to achieve equivalent heating performance is approximately half that required by conduction.

b. Flexibility in acceptance of food package shape seems desirable since orbiter life is 10 years and food systems may change.

c. Elimination of electrical connectors for each insert increases reliability.

d. Overall performance reliability considered high due to multiple blower use with only some degradation occurring in the event of a single blower failure.

e. Cost is likely to be less because 21 separate control systems are eliminated.

8.2 Future Work

8.2.1 Frozen Food Interface with Galley

The inclusion of a frozen food locker, separate from the galley, will require some interface study. Specific areas of study include:

a. Frozen food overwraps

b. Means of transportation of frozen foods to the galley

c. Provision in galley to store frozen foods during loading of the food tray inserts

8.2.2 Trash Study

With the likelihood of increased trash volume of cans over its stowed configuration, additional trash containment may be required. A study should determine the trash compaction that could be achieved with an acceptable operational complexity and crew time. The galley envelope should be examined for alternate trash containers or possibly areas outside of the galley should be sought.

8.2.3 Package Standardization

The use of round aluminum cans and square plastic packages present obvious incompatibilities throughout the system. Significant improvements in storage volume, trash volume, handling times, oven complexity and tray interfaces could be achieved if all packages were standardized to a square shape.

END